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BIO-MEDICAL DIVISION PRELIMINARY REPORT FOR PROJECT SCHOONER

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Dr. Richmond

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Bio-Medical Division

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Abstract

The Schooner Event was a 31-kiloton nuclear cratering detonation executed on 8 December 1968 at the Nevada Test Site. The Bio-Medical Division participated in this event in a variety of ways concerned with prediction, transport, and interaction with the biosphere. The predictive effort considered those radionuclides created within the device and its environment with the aim of identifying those with the greatest biological hazard. During and immediately following the event a variety of field experiments were conducted. Aircraft samples of the cloud were analyzed to determine radionuclide and mass partitioning as a function of particle size and class. Fourteen sequential air-sampling stations were fielded to study the distribution and redistribution of airborne particulates up to 6 weeks following the event. Considerable redistribution of debris was found, with the stations initially upwind recording very high activity four days after detonation. Pigs were stationed at four sites in the field for studies of the fate of radionuclides inhaled and ingested under field conditions. Fallout trays and tritium sniffers were fielded to document the mass deposition and radionuclide specific activity of fallout material and the tritium content of the base-surge cloud. In a joint project with Plowshare Division, more than 300 parachute-borne air samplers were dropped through the cloud to determine the total cloud burden. Two high-volume debris separators and collectors were fielded to collect large amounts of debris from the base-surge cloud for laboratory experiments on the biological availability of radionuclides in fallout debris. Several additional field and laboratory experiments were begun after detonation. With debris collected from the base-surge cloud as well as with crater-lip material, experimenters are determining the biological availability of radionuclides to pigs, cows, and various aquatic organisms. The leachability of debris radionuclides is being determined in a variety of solvents, and the biological availability of the nuclides to aquatic animals is being assessed. An ecology program was begun in the immediate vicinity to study the half-residence-times of radionuclides in soils, plants, and animal life. Surveys of the residual soil contamination and in situ biological availability of radionuclides are also being conducted at distances 50 miles from ground zero. Many of these experiments are continuing projects. This report summarizes preliminary findings and indicates the direction of continuing efforts.

Introduction

The Schooner Event, executed on 8 December 1968, was a 31-kt nuclear cratering detonation in the general series of excavation experiments conducted by the Division of Peaceful Nuclear Explosives of the Atomic Energy Commission, and directed by Plowshare Division, Lawrence Radiation Laboratory, Livermore, California. The purpose of the Schooner experiment was to investigate the physical and chemical parameters of the detonation medium that affect cratering phenomena at low and low-intermediate explosive yields.

The detonation site was on the northern edge of Pahute Mesa at the Nevada Test Site at an altitude of 5565 ft above mean sea level (MSL). The emplacement hole (U20u) was located at approximate Nevada State coordinates N944, 014, E529, 282. The local geology was composed of flat-lying strata of welded and nonwelded tuff to a depth of 1000 feet. Tuff is rock of igneous origin, made up of fine fragments of volcanic ejecta or ash that have been cemented or welded in varying degrees. Coarser volcanic ejecta form a breccia and upon cementation and compaction the finer ash produces a tuffaceous rock. The shot medium was made up of strata of various kinds of tuff and tuffaceous sandstone with a wide variation in water content. A complete description of the Schooner detonation site and medium is given by Tewes[1] and Ramspott.[2]

The predicted dimensions of Schooner crater, assuming a 40-kt yield with simple scaling relationships, were 270 ± 90 ft depth, 400 ± 100 ft radius. Certain characteristics of the shot medium resulted in greater than expected cratering efficiency, and the dimensions of the Schooner crater are larger than predicted. Figure 1 is an aerial photograph of the Schooner crater shortly after its creation.

The Schooner Event may be considered an important experiment in the cratering series leading to the use of nuclear explosives for a Central American trans-isthmian canal. One of the primary purposes of the Schooner experiment was the verification of calculational codes that predict the performance of nuclear explosives in various detonation media. Data in the low-to-intermediate range of explosive yields were needed for more competent geological media than alluvium, in which the 100-kt Sedan detonation was conducted. The Schooner detonation provided information on this subject and, to date, is the highest-yield detonation conducted in a hardrock medium.

The attendant environmental and biological factors associated with the Schooner experiment also provided an opportunity for LRL Bio-Medical Division scientists to evaluate the fate of radionuclides released in the event and their behavior in certain natural and experimental biological systems. The data also are extremely pertinent to the civil use of nuclear explosives because, of all the problem areas associated with such projects, the release of radioactivity into the uncontrolled environment and its impact upon public health may be the limiting factor.

In the experimental plan for Project Schooner by Tewes,[1] nine areas of participation by the LRL Bio-Medical

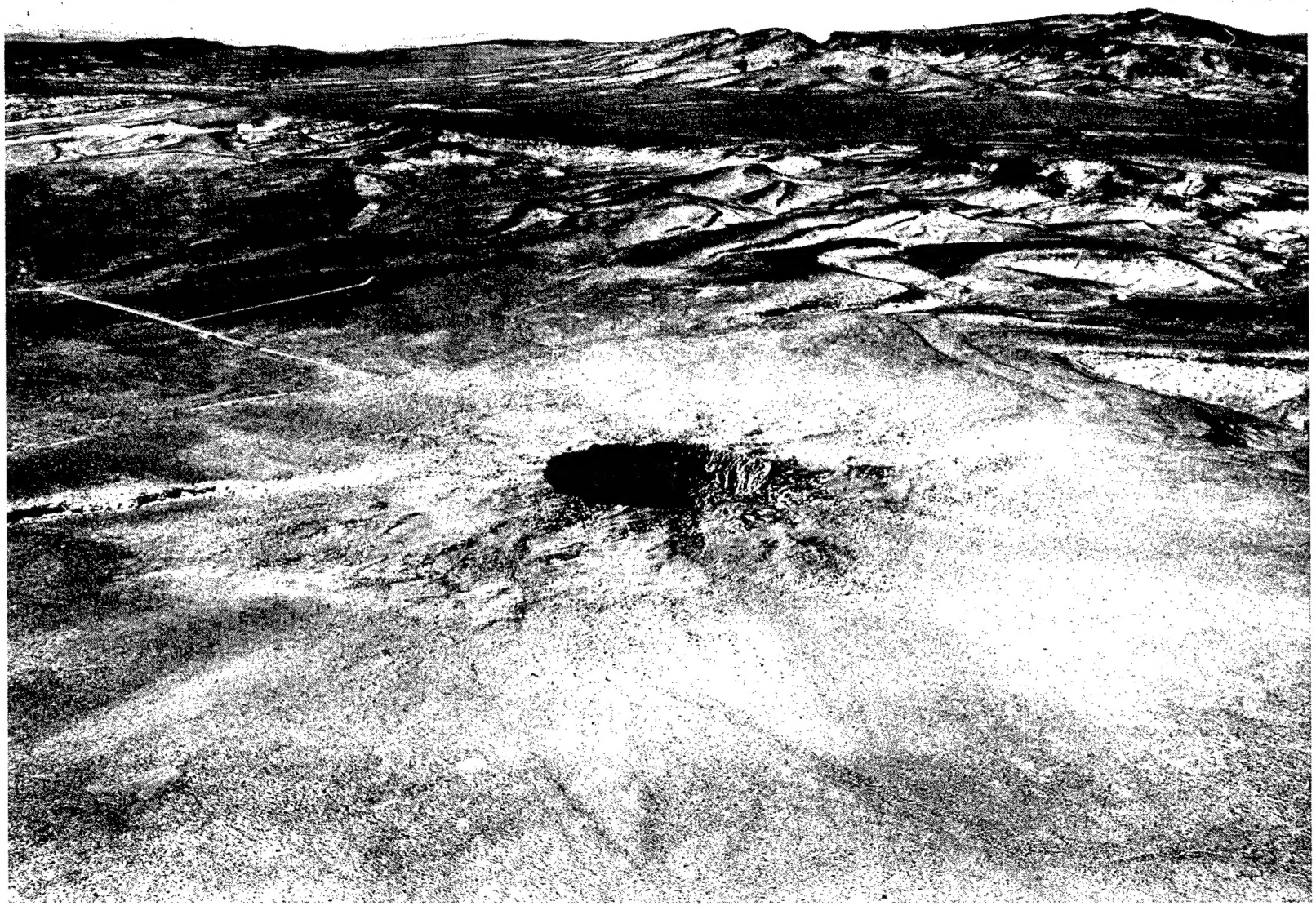

Fig. 1. Aerial view of the Schooner crater.

Division were described. Certain of these areas involved measurements made at shot-time or soon after. Other areas of research by Bio-Medical Division scientists, e.g. ecological studies, are long-term projects whose execution will require longer periods of time. This report is concerned with the preshot predictions, the shot-time measurements, and biological experiments, and includes descriptions of the methods and specially designed instrumentation employed in these studies.

The following outline describes briefly the areas of research conducted by the Bio-Medical Division in the Schooner Event and discussed in detail in this report.

I. Preshot prediction of the biological significance of radionuclides produced in the Schooner detonation.

II. Shot-time and early-time physical measurements.
   - A. Fallout collection in 2 × 2 ft trays within the 2-mile arc.
   - B. Collection of airborne particles by specially designed sequential air-samplers placed at distances up to 50 miles from surface ground zero (SGZ). These samplers were maintained for up to 6 weeks after the event to study the redistribution of deposited radioactive particles.
   - C. The collection by a high-volume cyclone air-sampler (Sadsac) of large quantities of particles of different size classes for biological experiments.
   - D. Determination of the radionuclide concentration in various sizes of particles produced and transported from the detonation site.
   - E. The concentration of tritium as THO in the base-surge cloud.
   - F. The early-time concentration of tritium as THO in bulk ejecta and missile ejecta.
   - G. The specific activities of radionuclides in Schooner ejecta from the crater lip out to 10,000 feet.

III. Biological measurements and experiments.
   - A. The concentration of radionuclides, including tritium, in the organs and bones of small mammals living in the vicinity of Schooner crater at early times.
   - B. The availability to dairy cows of radionuclides in Schooner ejecta and fallout.
   - C. The biological availability to pigs of radionuclides in Schooner debris.
   - D. The leachability by various aqueous solutions of radionuclides in Schooner ejecta.
   - E. The biological availability to aquatic organisms of radionuclides in Schooner ejecta and fallout.
   - F. The persistence in the soil, and the uptake by the plants, of radionuclides in Schooner fallout deposited at far-out locations.

Preshot Prediction of the Biological Significance of Radionuclides Produced in the Schooner Detonation

Yook C. Ng

Two reports have been prepared that are concerned with the biological hazards resulting from the radioactivity produced in the Schooner Event. The first estimates the maximum internal dosage that could result from Schooner and discusses the critical unknowns that are required for an adequate prediction of the dosage.[3] The dosage estimates indicate that of the three sources, fission, device activation, and soil and rock activation, device activation appears to be the most important contributor to the bone and whole-body dosages. Unless substantially less than 10 percent of the isotope is released to the atmosphere on small particles, the dosage from tungsten isotopes would exceed that from fission products and activation products of rock and soil. The cricitcal unknowns that determine body burden and dosage from the radionuclides released to the biosphere in Schooner are the following:

1. The actual production of the isotopes singled out as the most important.
2. The actual production of the potentially hazardous nuclides produced by charged-particle reactions and neutron reactions having unknown cross-sections.
3. The number of neutrons released to the environment.
4. The fraction released to the atmosphere on small particles for each nuclide of importance.
5. Biological data for selected elements, including uptake and retention data and data on distribution in the biosphere.
6. Biological availability for essentially all the nuclides of importance.

The second report describes an analysis to assure that biologically important nuclides would not be produced in unexpected amounts in device materials or in the rocks surrounding the device.[4] Implementation of the procedures of Burton and Pratt[5] established the limiting concentrations of trace elements in the device and in the rocks surrounding the buried device. On the basis of this evaluation few measurements had to be made to minimize the likelihood that biologically important nuclides would be produced in unexpected amounts in the device or in the rock and soil surrounding the device.

Distribution and Redistribution of Airborne Debris from the Schooner Event

Lynn R. Anspaugh, Paul L. Phelps,
Gale Holladay, Stanley R. Bishop,
John C. Taylor, Vance G. Fowler,
Keith O. Hamby, and William E. Bell

Introduction

To what extent should the redistribution of nuclear debris from a cratering event be considered in evaluating the biological hazards of radioactive particulate to man?

An experimental program to aid in answering this question was designed by the Bio-Medical Division and fielded on Project Schooner. It was designed to answer only those questions that could be dealt with by carrying out experiments of the first order with the funds available. The ultimate questions were to be reserved for more sophisticated experiments to be conducted at a later time, if indeed they were justified by the preliminary findings.

Our experiments were directed specifically to the following questions:

1. Does redistribution occur under the influence of changing meteorological conditions, primarily the winds?
2. If so, to what extent does it occur?

To answer these questions, radioactivity concentrations in the air were monitored with sampling equipment activated by a predetermined radiation level. These units were fielded and allowed to operate over a 50- to 1000-hr period following detonation. The sampling was accomplished with sequentially operated air-pumps under the control of an electronic programmer (see the following section).

Although the primary emphasis of this experiment was on airborne activity, ground deposition and residual soil activities were also measured in cooperation with other groups. These latter experiments will be covered in conjunction with the air activity measurements.

The results show that significant redistribution of debris can and does occur, indicating that models considering only the conditions at shot-time may fail to adequately predict biological hazards. They also show that contamination occurred off-site following the Schooner Event, and that long-term ecological studies on biological availability are feasible in situ at these contaminated sites.

SEQUENTIAL AIR SAMPLER

The sequential air-sampler consists of a set of air pumps for sampling airborne radioactive debris. Once the system has been triggered by the predetermined radiation levels, the pumps can be operated sequentially under a programmed timing schedule. Its function is to collect particulate from large volumes of air over selected periods of time for later analysis by gamma-ray spectroscopy.

The remote location of the Schooner excavation experiment and the possible

presence of elevated levels of postshot radioactivity at locations on the close-in (6-mile) arc imposed the need for the samplers to be self-powered, self-starting, and able to run for long periods unattended. Equipment at the more distant locations (50-mile arc) were not equipped with automatic features but were started manually at various times after detonation. Proper consideration was given to the somewhat severe environmental conditions often encountered at the Nevada Test Site. Further constraints on system design were imposed by short development and procurement time and limited equipment funds: the selections of components was confined to inexpensive, quickly available commercial items. Emphasis was on a workable, reliable design.

The resulting system (Figs. 2 and 3) consists of a bank of up to seven sampling heads mounted on a wooden saw-

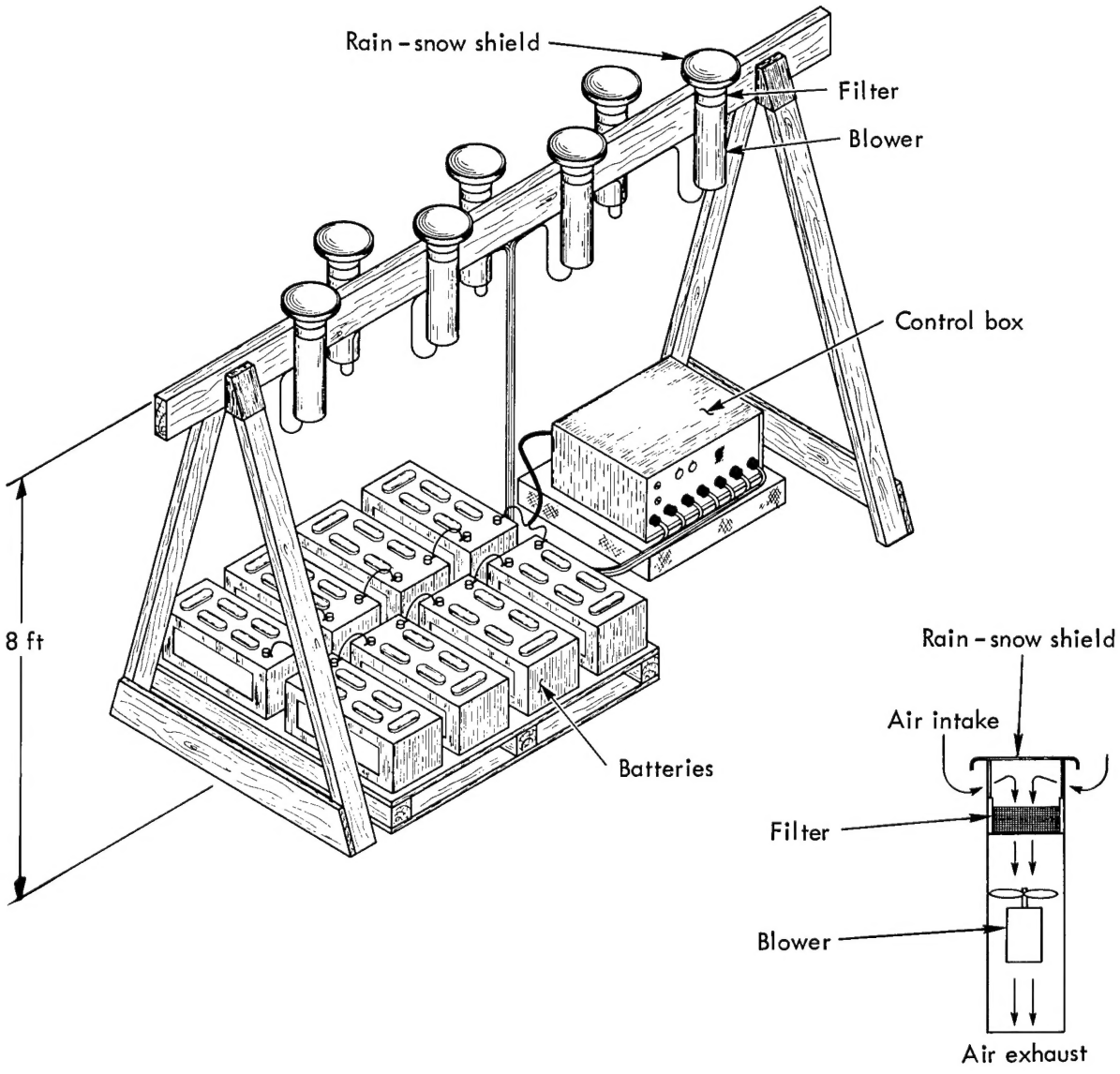

Fig. 2. Schematic diagram of the sequential air-sampling system.

Fig. 3. A nearly completed sequential air-sampling station. The crosspiece holds the sampling heads 7 ft above the ground. A rope is slung under the battery pallet to secure the samples against upset by wind or shock wave.

horse, an electronic timing chassis that controls operating period and sequence, a starting circuit activated by a gamma detector, and a lead-acid battery power supply.

ELECTRONIC TIMER

A simple timing unit was developed for sequentially programming the blowers. The timing unit has solid-state components and electromechanical stepping switches to provide a wide selection of time periods and very low power consumption. Provisions were made for sequencing up to 12 blower units. The unit may be operated either in an exponential timing mode or in a linear mode

with either minutes, hours or days as the basic time unit.

A unique capability of the timer is the exponential mode, which is expecially adapted to the conditions immediately following a nuclear cratering event. It provides progressively increasing time periods, each of which is twice as long as its predecessor; this prevents overloading of the early filters and inadequate quantities of sample in the later filters.

SAMPLING HEAD

The sampling head (Fig. 4) is made up of a small commercial vacuum cleaner slightly modified to take a convoluted fiberglass filter. Flow rates of either 10 or 20 ft^3/min, depending upon the battery voltage selected, were achieved with the air pump and filter.

No attempt was made to design an isokinetic sampling system. However, calculations indicate that particles of diameter $<50\ \mu$ were extracted from the air, and it is with particles below this size that the primary biological hazards are associated.

FILTER

The filter is one of the key components for a satisfactory system. Desirable filter properties include: (1) high collection efficiency for particles of interest, (2) ability to collect large amounts of particulate without serious loss of flow-rate, (3) high flow-rates for a given pressure drop, and (4) low cost and easy availability.

To meet these requirements, a commercial filter of convoluted fiberglass (Mine Safety Appliance Company MSA-77227) was selected.* The material of this filter is more than 99 percent efficient for particles down to 0.025μ,[6] and gives a flow rate of 50 ft/min with a pressure of 10 in. of water applied. The pleated construction provides an effective area of 77 $in.^2$ in a size that fits neatly into the aluminum can widely used by the Bio-Medical Division for packaging its samples of counting.

AIR VOLUME

Since it was not economically feasible to directly measure and record air flow under field conditions, the air flow was calculated from manometer and battery voltage measurements made when the filters were installed and again when they were retrieved.

The air-flow rate is obtained from the manometer reading of pressure differential by the relationship shown in Fig. 5. This curve was derived from a laboratory experiment in which the air-flow rate was measured directly and correlated with the pressure drop across the filter. Since this experiment was performed at Livermore, however, air-flow rate values computed from Fig. 5 must be corrected by multiplying by the ratio of Livermore air pressure to local air pressure at the sampling site.

A further correction must also be made because the actual pressure differential is

*Reference to a company or product name does not imply approval or recommendation of the product by the U. S. Atomic Energy Commission to the exclusion of others that may be suitable.

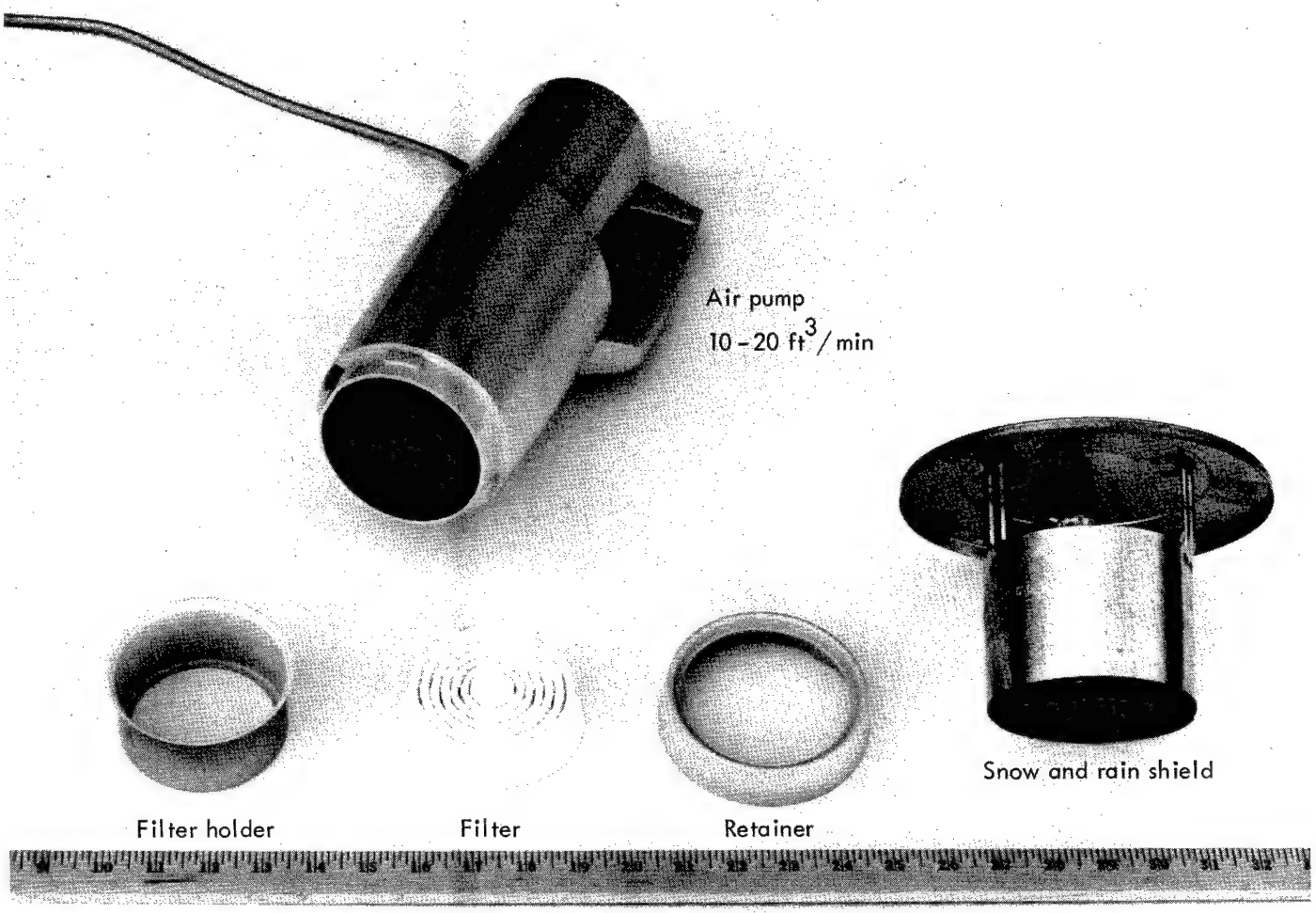

Fig. 4. A sampling head, disassembled.

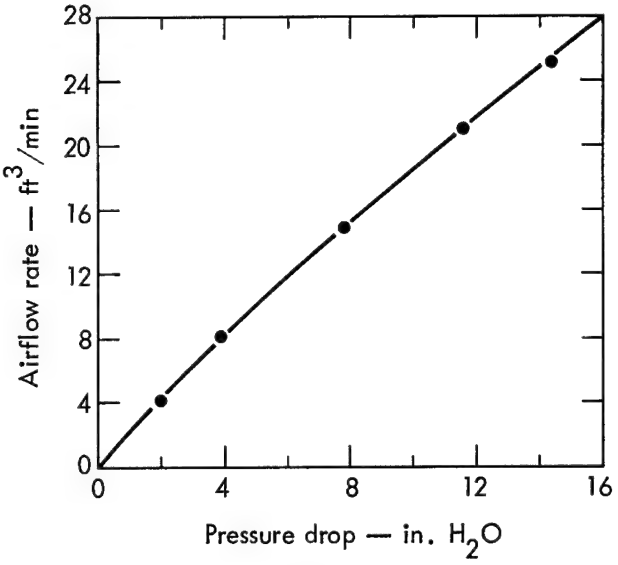

Fig. 5. The relationship between airflow rate and pressure drop across the MSA sequential air sampler filter.

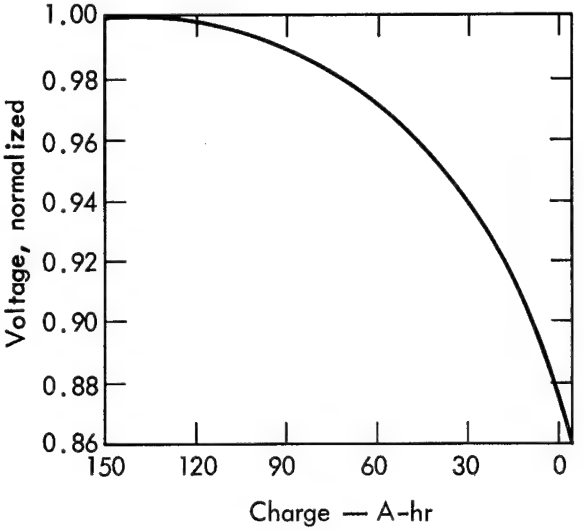

Fig. 7. Normalized battery voltage for a 150 A-hr lead-acid battery as a function of battery charge.

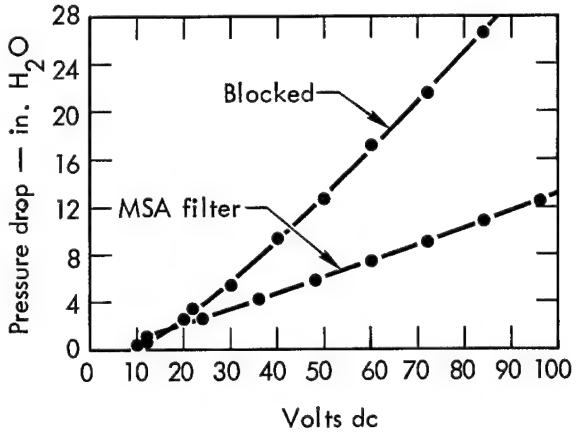

Fig. 6. The relationship between the pressure drop across the filter and a blocked filter as a function of voltage applied to the air pump (Sears Vacuum Cleaner Model-7150).

not constant but is proportional to battery voltage (Fig. 6), which changes as a function of battery charge. The average pressure differential across a filter during its exposure period is therefore calculated by multiplying the initial manometer reading by a normalized battery voltage. The normalized battery voltage is the ratio of the voltage of a partially charged battery to that of a fully charged battery; it varies as shown in Fig. 7 with the kind of battery used. A battery-charge status curve (Fig. 8) was prepared for each station showing the amount of battery charge remaining in the battery at the midpoint of each filter run.

Table 1 is an example showing how these computations were made for the first sample set on Station 5.

FILTER RECOVERY

When the filters were recovered, several items were checked to evaluate system operation, particularly with respect to determination of the times of filter exposure and the volume of air passed. Battery voltage was measured and recorded for use in constructing the battery-charge curve, as mentioned earlier. The position of each stepping switch in the timer was recorded for calculating the exact time period for each air pump. A

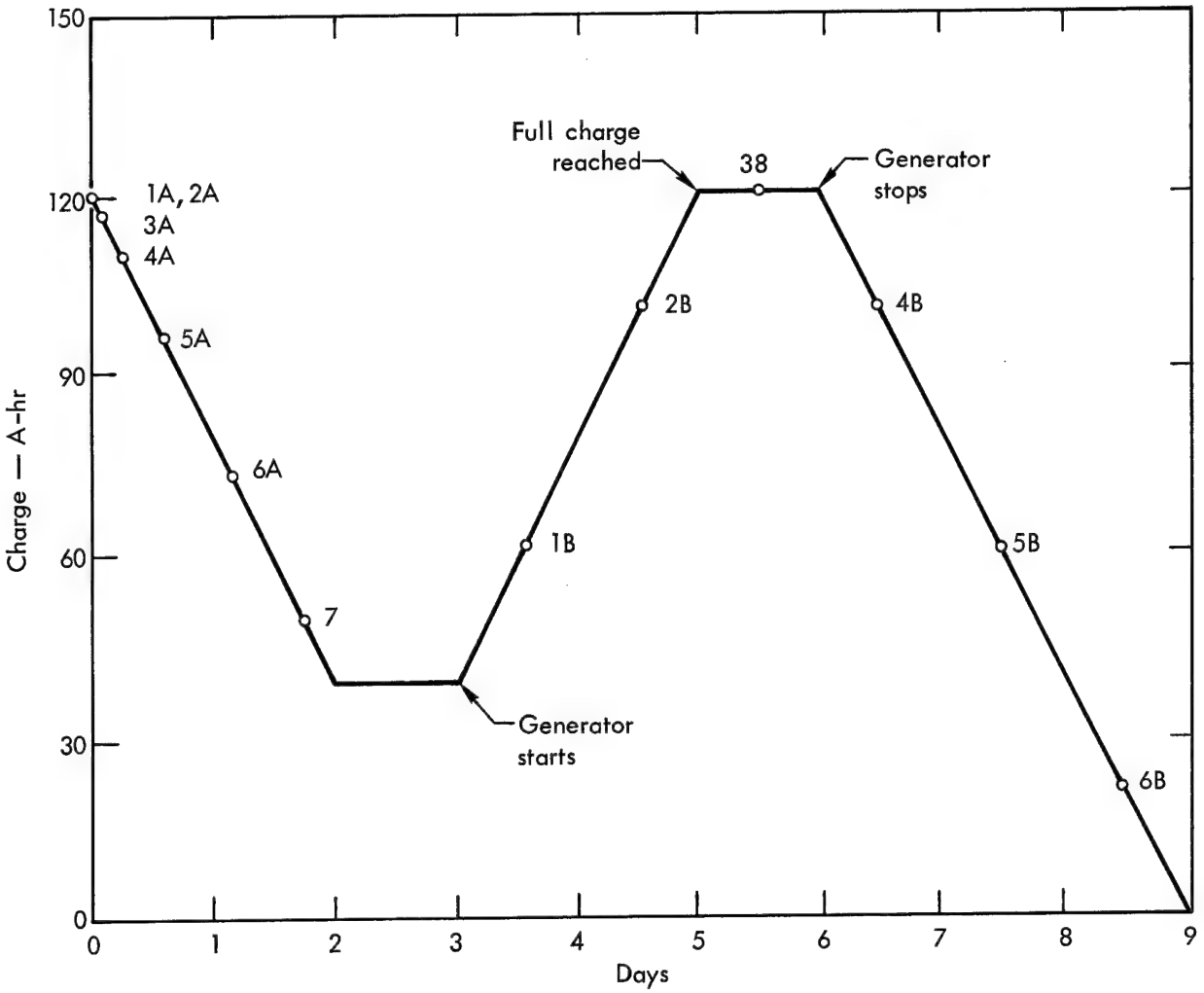

Fig. 8. Battery charge-status curve for Station 5 over a 9-day sampling period. The numbers on points are the sample numbers.

Table 1. Typical data for maintaining the air-volume history for the sequential air-sampling stations.

Filter No.	Initial ΔP (in.)	Est. battery voltage[a]	Est. ΔP (in.)	Flow rate (ft^3/min)		Time (min)	Sample volume (ft^3)
				Uncorr.	Corr.[b]		
S5-1A	8.5	1.00	8.5	16.0	18.9	30	570
S5-2A	9.2	1.00	9.2	17.2	20.3	60	1,220
S5-3A	8.5	1.00	8.5	16.0	18.9	120	2,270
S5-4A	7.6	1.00	7.6	14.5	17.1	240	4,100
S5-5A	8.0	1.00	8.0	15.2	17.9	480	8,600
S5-6A	8.0	0.99	7.9	15.0	17.7	960	17,000
S5-7A	7.9	0.98	7.7	14.7	17.3	960	16,600

[a]Normalized.

[b]Corrected for altitude.

final manometer reading was taken, to check for blower deterioration and filter loading, and to verify estimates of cubic footage based upon the initial manometer reading. To minimize cross contamination between filters on recovery, disposable gloves and tissue wipes were used to remove each filter and holder. Each filter was then sealed separately in a plastic bag. The filters were compressed to uniform thickness and sealed in a 5-mil-thick, 200-cc aluminum can.

SAMPLE ANALYSIS

All samples were returned to the counting laboratory at the Bio-Medical Division (LRL) for analysis. All identifiable gamma-emitting radionuclides are being quantitated using our large-volume, germanium-lithium-drifted detectors.[7]

AIR-SAMPLER LOCATIONS

The physical locations of the various sampling stations are indicated in Figs. 9 and 10. The site of the Schooner cratering experiment was the extreme northwest corner of the Nevada Test Site. Our most distant measuring stations were located on Highways 6 and 25. Airborne radioactive particulates were collected as a function of time over the 50-hr postshot period at locations T1, T2, T3 and T4.

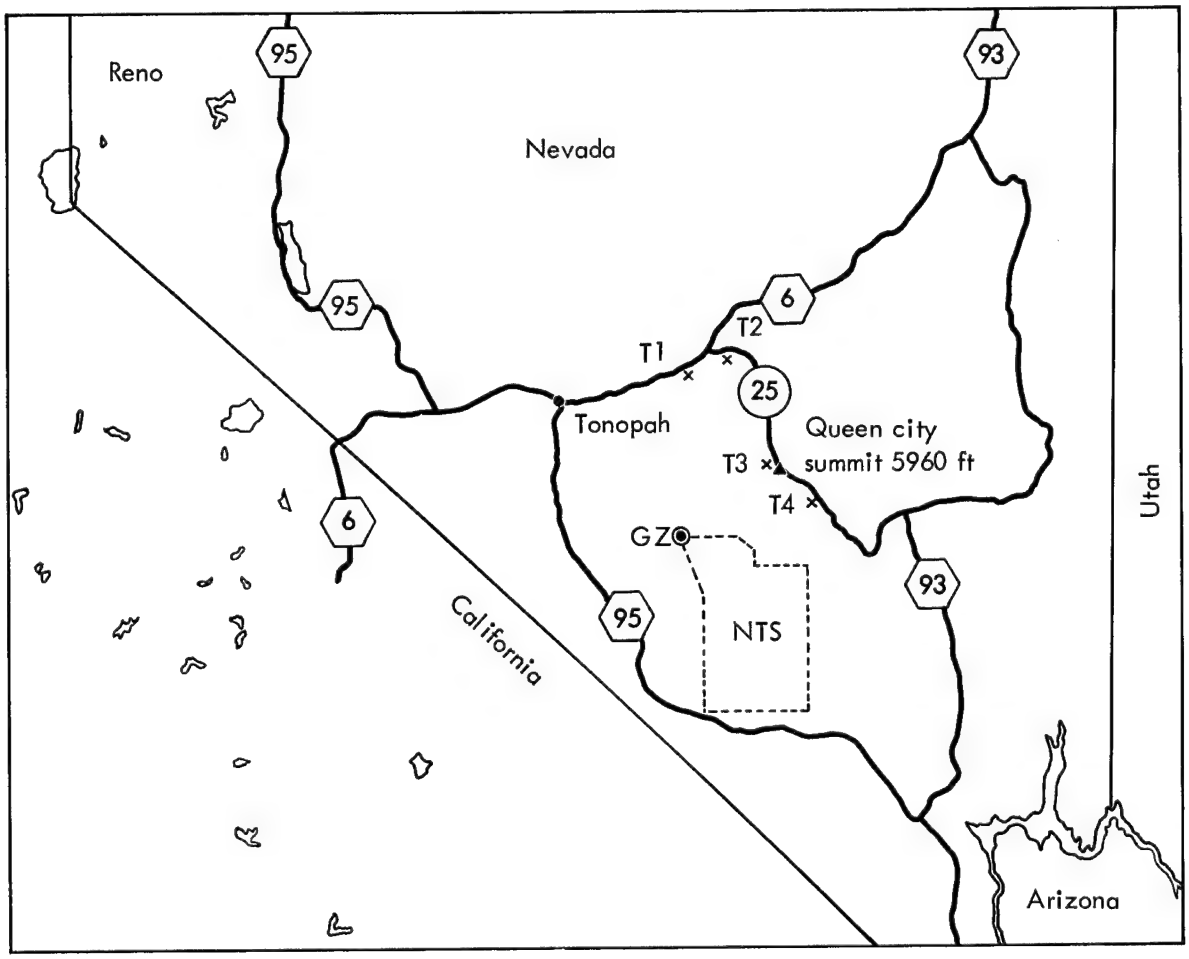

Fig. 9. Locations of the sequential air-sampling units (T1, T2, T3, T4) on the 50-mile arc.

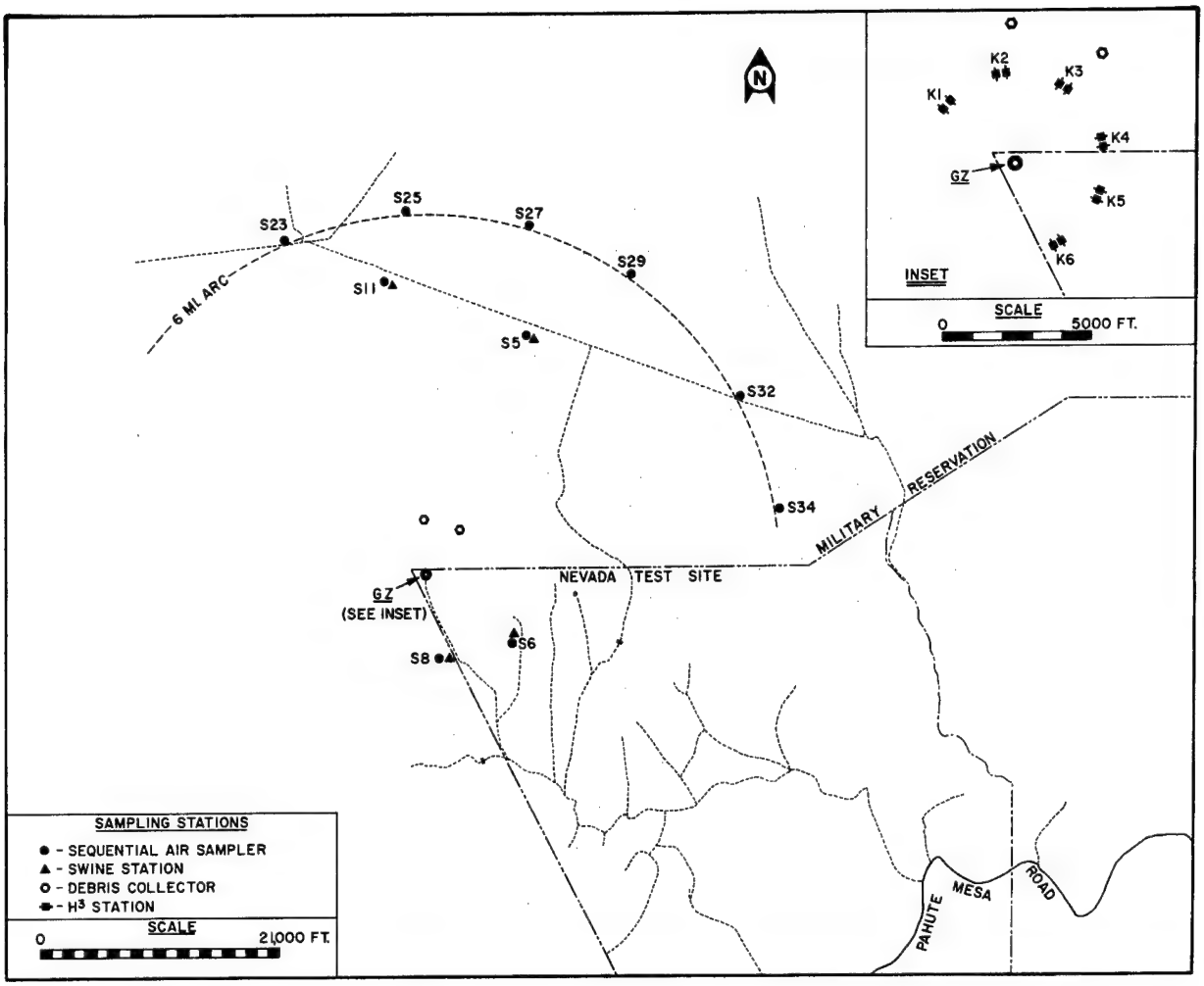

Fig. 10. Locations of all of the Bio-Medical Division's close-in field instrumentation.

Ground deposition was also collected at some of these locations and at other locations in the cooperative Sticky Tarp program directed by the U. S. Army Nuclear Cratering Group.[8] Figure 11 shows the location of the Sticky Tarp samplers as well as the far-out sequential air-samplers.

RESULTS

Detailed analysis of the radionuclides present in the air-filter samples is incomplete because of the large number of samples. A representative spectrum of the first sample from Station 32 is shown in Figs. 12, 13 and 14. It was obtained on D + 11 days, by which time several short-lived nuclides had already decayed. As predicted, the most predominant activities at fairly early times were due to the isotopes of tungsten.

One of the tungsten isotopes, ^{181}W, is unique in that of all the isotopes with fairly long half-lives it has low energy peaks (Ta fluorescent X-rays) that can be rapidly quantitated with a NaI(Tl) detector with pulse-height selection. The ^{181}W activity was therefore determined readily for all samples from all stations; the results are shown in Figs. 15 through 17. All of the plotted data are corrected to zero time; hence,

the decreased activity shown does not include the additional real decrease due to radioactive decay. This does appreciably affect the results for ^{181}W, however; even for the last measurements at H + 1400 hr, the ^{181}W activity would be decreased by only 25 percent. The length of each horizontal bar in the graphs represents the time interval during which each air pump was actually in operation. For purposes of comparison, the maximum permissible air concentration (MPC) for occupational workers for ^{181}W (with the lung as the critical organ) is 4×10^4 pCi/m^3 for a 168-hr week and 10^5 pCi/m^3 for a 40-hr week.[9]

There are several points of interest in Figs. 15 through 17. All stations except T3 and T4 probably sampled primarily the activity in the base-surge and very low

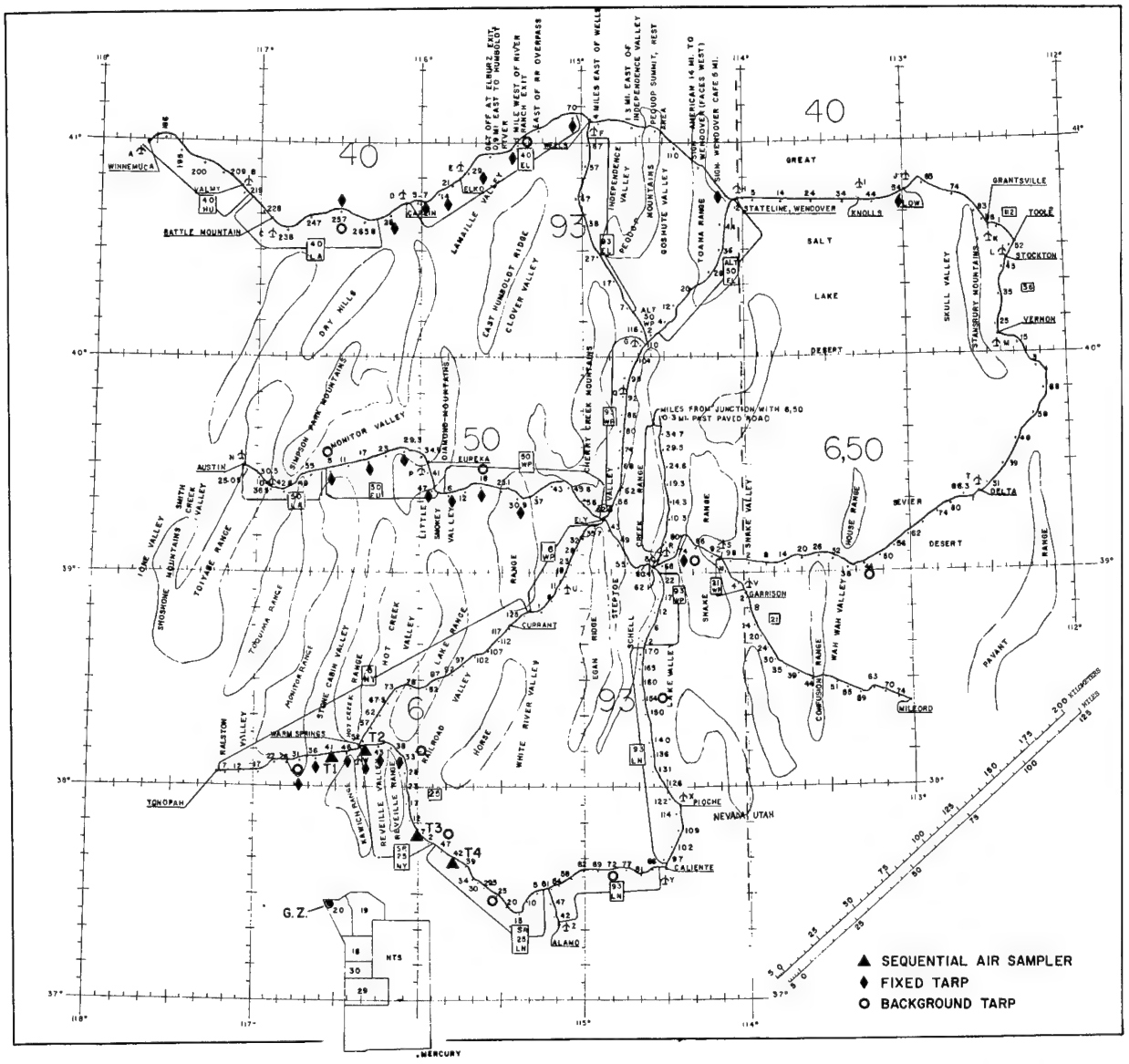

Fig. 11. Locations of the ground-deposition samplers fielded by the cooperative Sticky Tarp Program. Also shown are the locations of the four far-out Bio-Medical sequential air-samplers (T1, T2, T3, T4).

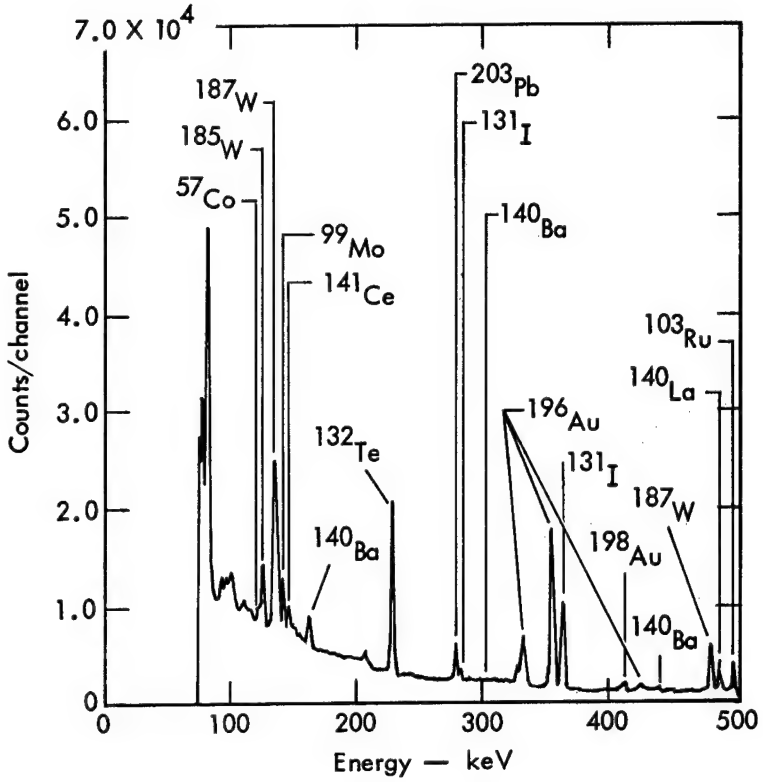

Fig. 12. A representative spectrum (channels 1 to 500 only) of an air-filter sample counted 11 days after the event. Calibration 1 keV channel; counting time 1152 min; system E-1; counted 19 December 1968.

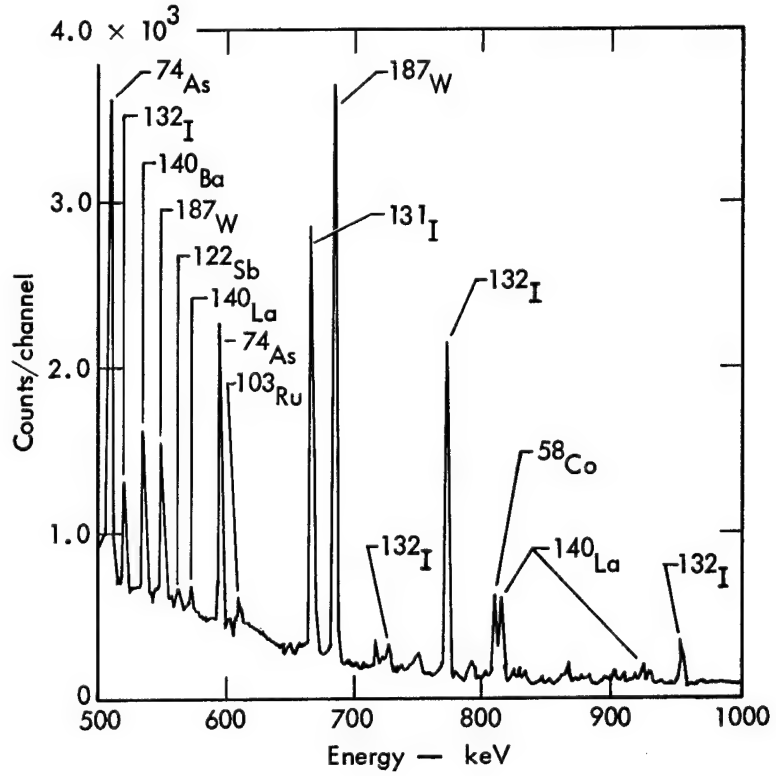

Fig. 13. The same spectrum as Fig. 12, but channels 501 to 1000 only.

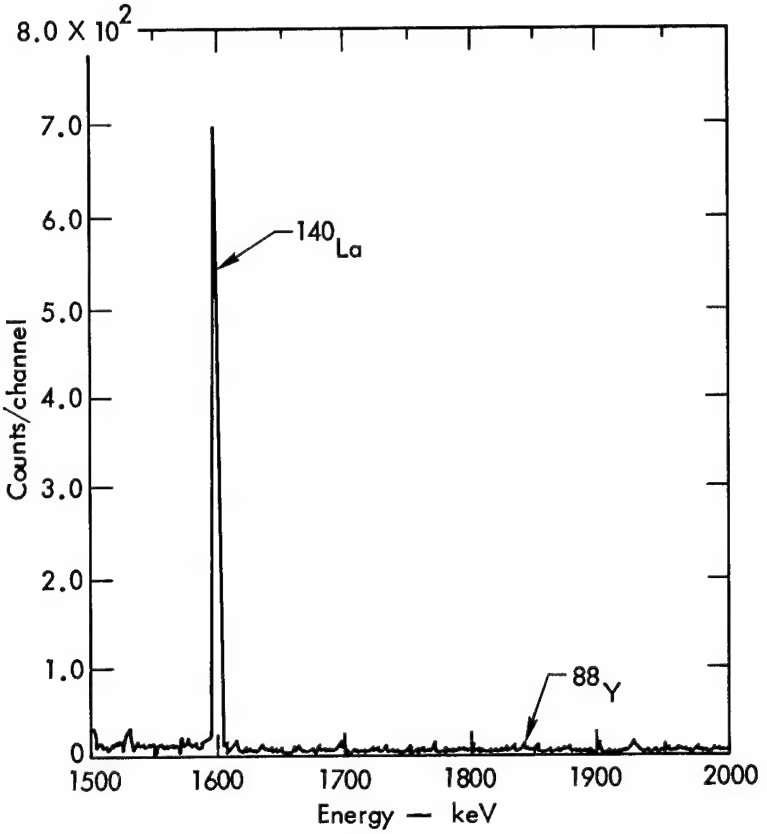

Fig. 14. The same spectrum as Fig. 12, but channels 1501 to 2000 only.

cloud, since there was an inversion layer and an associated wind shear at shot-time that took the high cloud in an east-northeast direction, whereas the base-surge went nearly due north. The close-in, downwind Stations 5, 11, 23, 25, 27, 29 (Fig. 15) and 32 (Fig. 16)* all showed high activities at early times, but did not show cloud passage as an abrupt event. The air activity remained high over extended time intervals indicating either that appreciable low-lying activity remained in the area, that significant amounts of material from the fallout field were being resuspended, or that activity was still streaming from the crater. A comparison of the data from Stations 23, 25, 27, 29, and 32 (Figs. 15 and 16) indicates an inverse correlation between the initial air activity and the rate at which the activity disappeared from the air. This would appear to indicate that the activity over extended time periods is actually due to resuspension from the fallout field, since the wind direction was not constant throughout this time period.

Stations 5, 25, 27, and 29 (Fig. 15) all showed a marked secondary peak of activity at H + 30 hr to H + 50 hr which amounted to 10 to 30 percent of the maximum recorded activity at early times. Minor precipitation occurred in the area at H + 140 hr to H + 200 hr and significant amounts at H + 850 hr.

The behavior of Stations 6 and 8 (Fig. 16) is perhaps the most interesting with respect to resuspension and redistribution.

*The early samples from Station 34 were lost.

Since these stations were upwind at detonation time, low relative activities were recorded at early times. However, appreciable amounts of activity began to be recorded at H + 50 hr, and at H + 90 hr Station 8 recorded the highest activity of any station, despite the fact that it was not in the initial fallout field. Observers in the area noted severe windstorms during the period H + 72 hr to H + 80 hr.

Other data also show significant redistribution of debris on the ground. These consist of data taken by the EG&G Corporation NATS aircraft flying over the fallout field on three different days as requested by the LRL Radiochemistry Department. These data (Figs. 18 through 20) were taken with a highly collimated array of NaI detectors while the aircraft was flying

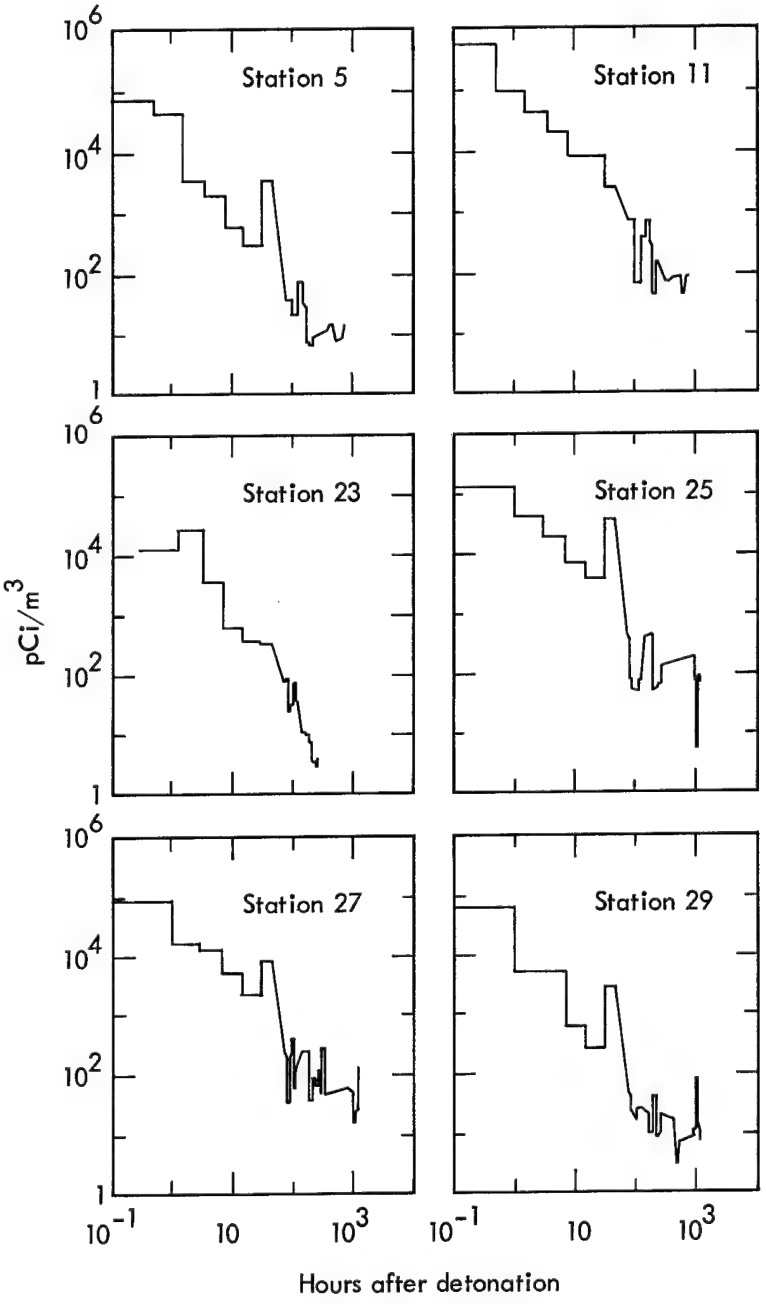

Fig. 15. The ^{181}W air activity as a function of time at six stations.

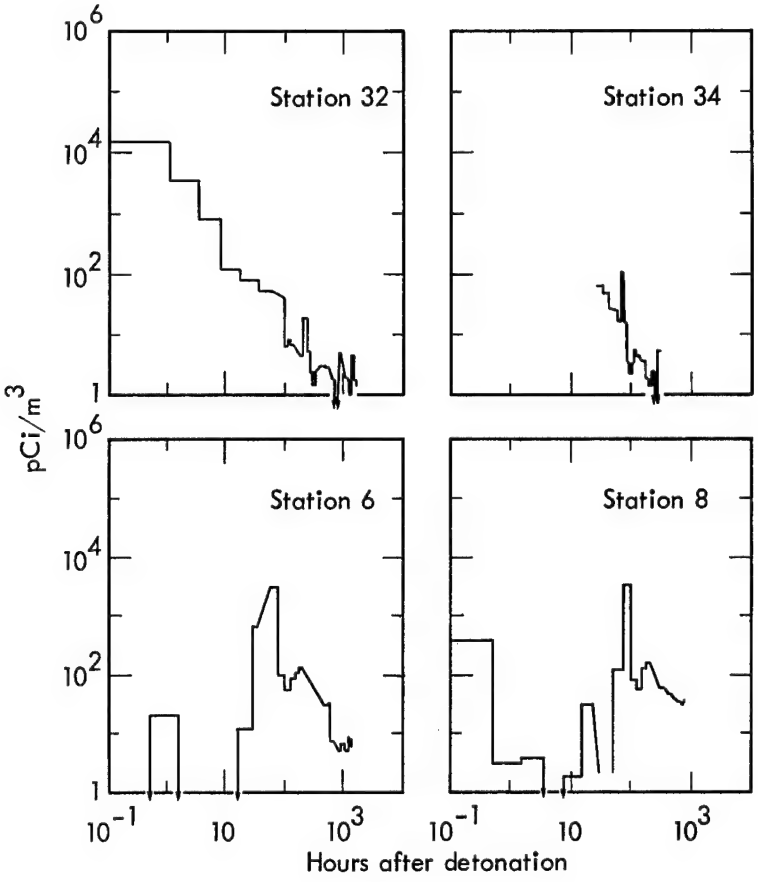

Fig. 16. The ^{181}W air activity as a function of time at four stations.

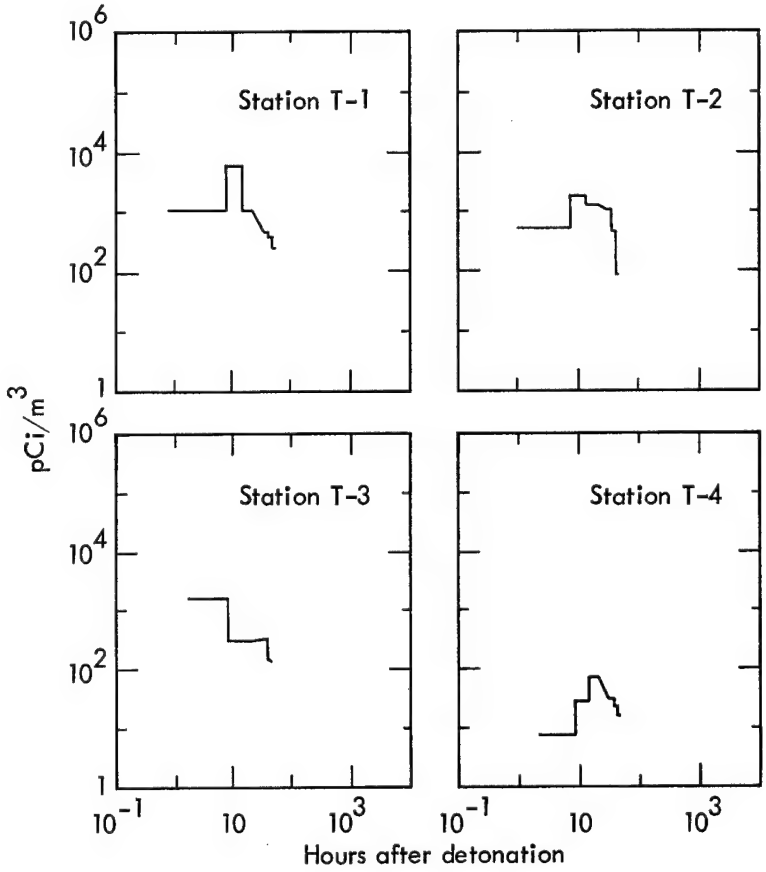

Fig. 17. The ^{181}W air activity as a function of time for the four far-out stations.

500 ft above the terrain.[10] Ground speed was 140 knots.

Figure 18 shows the data taken at D + 7 or H + 168 hr. This fallout pattern is consistent with that measured by Plowshare Division at early times in that the base-surge hot-line lies nearly due north and the main-cloud hot line lies to the northeast.[11] Note particularly the location of the 5X background contour line. Figure 19 shows similar data taken at D + 13 days or H + 132 hr. The fallout pattern is considerably contracted, as would be expected, and the 5X line is now about even with the dry lake. Shown in Fig. 20 are the data for D + 20 days or H + 280 hr. Note that the 5X contour line has expanded to a considerable extent beyond the dry lake, indicating that appreciable redistribution of debris has occurred.

The activity seen at the far-out stations is also most interesting. These stations, T1, T2, T3, and T4, were located approximately on the 50-mile arc from GZ and were situated close to public highways that were not closed during or following the Schooner Event. The air-activity data (Figs. 15 through 17) show that the leading edge of the cloud arrived some time before H + 7 hr and peak activity occurred between H + 7 hr and H + 13 hr. The highest far-out activity, recorded at Station T1, was about 1 percent of the highest early activity, which was recorded at Station 5. At H + 10 hr, Stations 11, 25, 27, and T1 were recording nearly equal air concentration activities in spite of their wide separation in distance.

As previously mentioned, the air samplers at Stations T3 and T4 probably sampled the bottom of the main cloud, whereas all the other samplers almost certainly sampled only the base-surge. The behavior of the air activity at Station T4, however, appears rather anomalous; the activity was one to two orders of magnitude lower than at the other three far-out stations and the peak activity occurred considerably later—at H + 14 hr to H + 20 hr. This seems odd, because Station T4 was not very far from Station T3 nor from Queen City Summit, the sites of the highest ground deposition levels as measured by the Sticky Tarp program.

The peculiar result at Station T4 is explainable in either of two ways: either the main cloud did not pass over this station or it was shadowed by topographical features. Station T4 was shielded from GZ by the Belted Range including Belted Peak at an altitude of 8202 feet, 16 miles in front of Station T4. In any event, it appears that the late air activity peak seen at Station T4 is of secondary nature, and probably due to lateral diffusion.

Table 2 summarizes the air activities and deposition data at the four far-out stations and also the deposition data at Queen City Summit. The data on ground deposition and open-field gamma dose-rates come from the cooperative Sticky Tarp program directed by the Nuclear Cratering Group. Also shown in Table 2 are the time intervals during which the peak air activities and the ground deposition were observed; the open-field gamma measurement was made at the end of the period shown under ground deposition. The data on residual soil activity are those of Grabske (this report, p. 70), which were taken during the first half of May 1969. These soil data were not corrected to zero time.

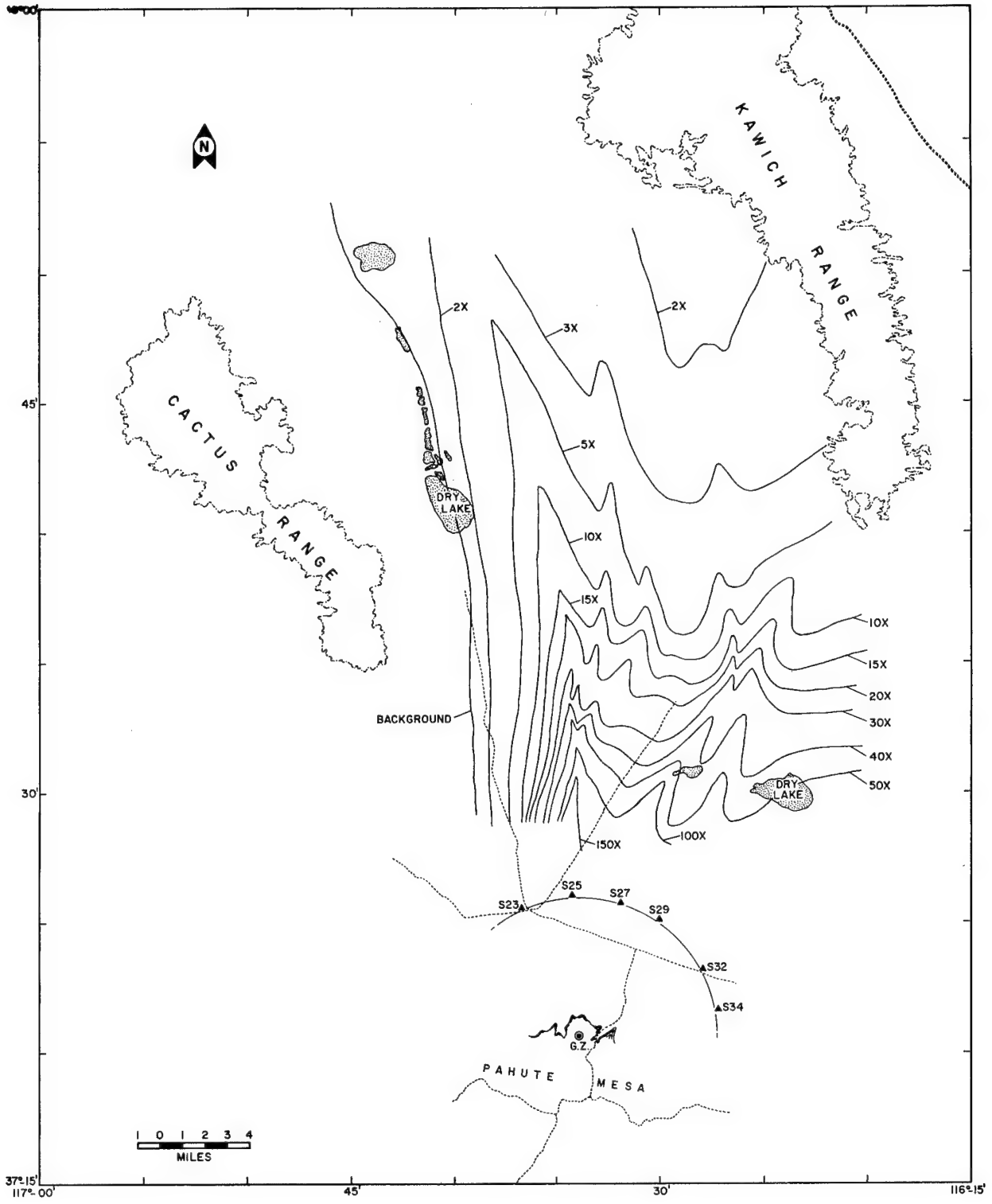

Fig. 18. Aerial measurement of the Schooner fallout field as measured by the EG&G Corporation NATS aircraft 7 days after the event. The contours represent multiples (2X, 10X, 50X, etc.) of background, which was ~15 to 20 μR/hr.

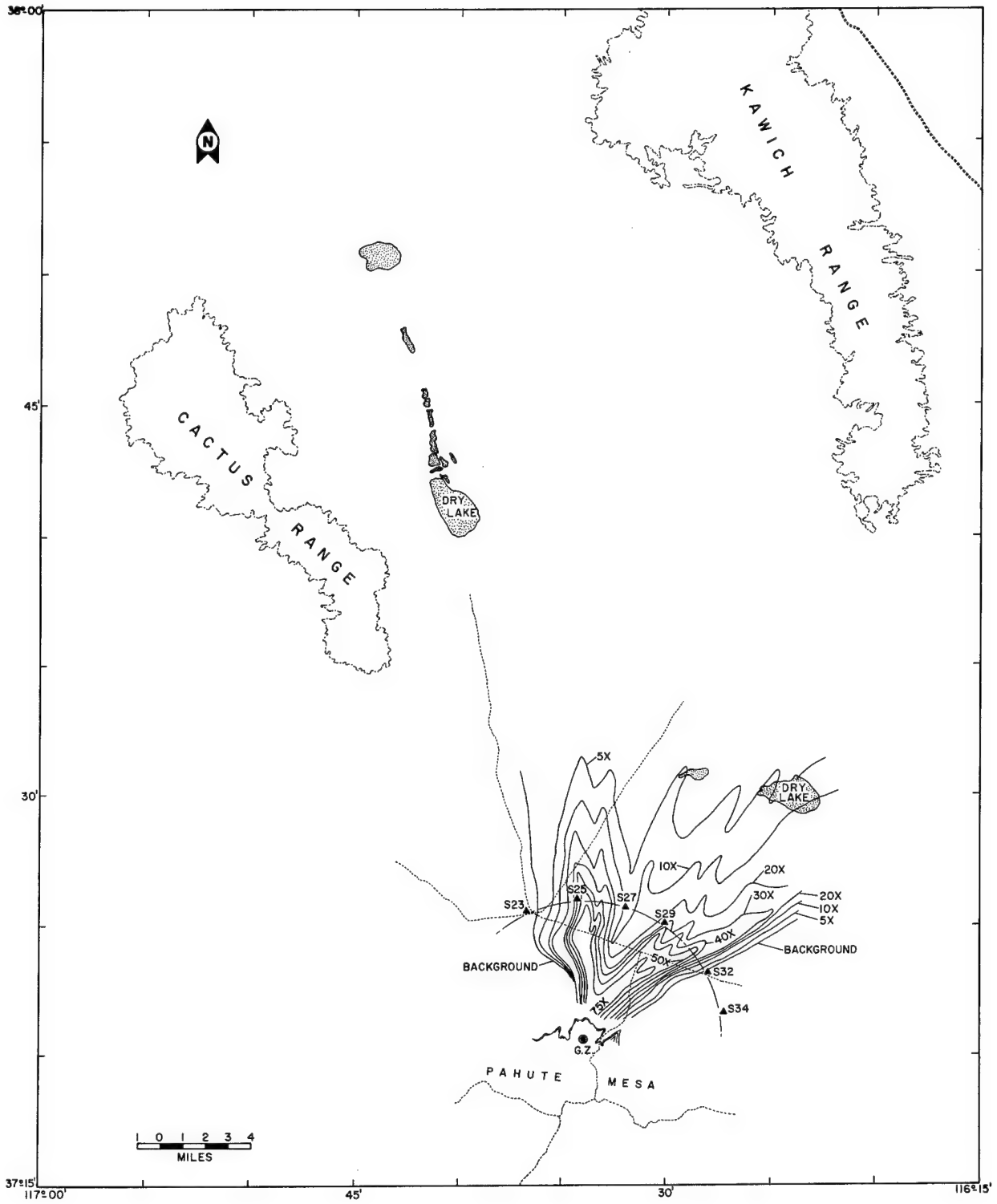

Fig. 19. Aerial measurement of the Schooner fallout field as measured by the EG&G Corporation NATS aircraft 13 days after the event. The contours are as explained in Fig. 18.

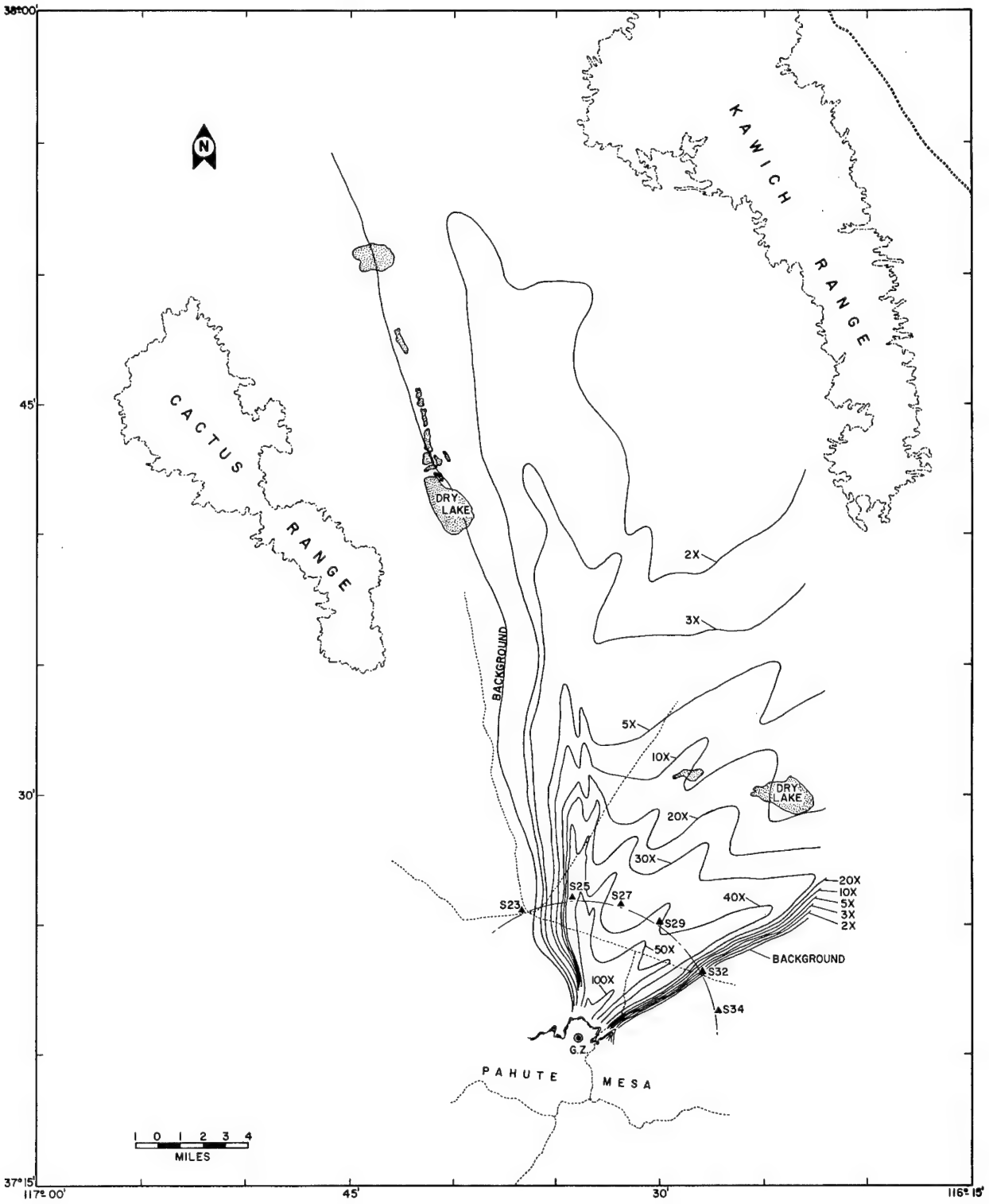

Fig. 20. Aerial measurement of the Schooner fallout field as measured by the EG&G Corporation NATS aircraft 20 days after the event. The contours are as explained in Fig. 18.

Table 2. Comparisons of peak air activity, ground deposition, and residual soil activity of ^{181}W at far-out locations.

Station	Location	Peak air activity (pCi/m^3)	Ground deposition (pCi/m^2)	Open field γ dose-rate (mR/hr)	Residual soil activity (pCi/m^2)
T1	55 mi, 5 deg[a]	6100 (H + 7 to H + 13)	3.3×10^5 (H + 3 to H + 12)	0.5	4.1×10^6
T2	65 mi, 15 deg	1800 (H + 7 to H + 13)	—	0.5	7.0×10^5
T3	43 mi, 43 deg	1700 (H + 2 to H + 8)	6.5×10^7 (H + 1 to H + 9)	15	—
QCS	44 mi, 51 deg	—	1.5×10^8 (H + 0 to H + 8)	130	3.0×10^8
T4	48 mi, 60 deg	66 (H + 14 to H + 20)	Background (H + 1 to H + 8)	0.014	—

[a]North = 0 deg.

Table 3. Air activity at Station 11 from H + 0.5 to H + 1.5 hours. All values corrected to zero time.

Nuclide	$T_{1/2}$	Activity (pCi/m^3)	Ratio: Activity / ^{181}W activity
^{74}As	18 d.	6.0×10^2	6.4×10^{-3}
^{88}Y	108 d.	7.0×10^1	7.5×10^{-4}
^{103}Ru	40 d.	3.3×10^2	3.5×10^{-3}
^{131}I	8 d.	1.3×10^3	1.4×10^{-2}
^{132}Te	78 h.	4.8×10^3	5.2×10^{-2}
$^{140}Ba/^{140}La$	13 d.	8.6×10^2	9.2×10^{-3}
^{141}Ce	33 d.	6.3×10^1	6.8×10^{-4}
^{181}W	121 d.	9.3×10^4	1.0
^{187}W	1 d.	6.9×10^6	7.4×10^1
^{196}Au	6 d.	2.9×10^3	3.1×10^{-2}

Several comments should be made concerning the data in Table 2. First, the Sticky Tarp at Station T1 was fielded rather late, at H + 3 hr. The open-field gamma reading at the time of fielding was 0.3 mR/hr, indicating that 60 percent of the total ground deposition occurred before the tarp was placed. This is also indicated by the considerably higher activity in the soil found some 5 months later. Secondly, although the data are not unequivocal, the ratio of ground deposition to peak air activity appears to be considerably higher for material from the main cloud than for the base surge. This seems reasonable because there would probably still be some gravitational settling from the high main cloud of particles too large to be sampled by our air pumps.

Up to this point only one isotope, ^{181}W, has been considered. Although our detailed analyses of the gamma emitters are far from complete, enough data are available to make a few preliminary statements. Of the approximately 100 samples analyzed so far, the data shown in Table 3 are typical of the quantifiable radionuclides present at fairly early times. The data are also expressed as a ratio to the ^{181}W activity as reference. Note that all activities except that of ^{187}W are far below the levels of ^{181}W. The levels of

^{185}W probably also would exceed those of ^{181}W by about a factor of three, although we have not quantitated this isotope which for all practical purposes is a pure beta-emitter. In addition to the 11 nuclides listed in Table 3, a few of the earliest counted samples also contained the short-lived nuclides ^{99}Mo, ^{198}Au, and ^{203}Pb. Also present in most spectra, but not yet quantitated due to interference, were ^{57}Co and ^{58}Co. For ^{74}As, ^{103}Ru, ^{131}I, ^{141}Ce, ^{187}W, ^{188}W, and ^{196}Au, the ratios of activity to ^{181}W activity appear to be quite constant as functions of both time and distance for all samples so far analyzed. The three isotopes ^{88}Y, ^{132}Te, and $^{140}Ba/^{140}La$ are exceptions to this.

Figure 21 is a plot of the $^{88}Y/^{181}W$ ratio for Stations 5 and 11. Station 5 appears to be anomalous; Stations 25 and 27 more closely resembled Station 11, al-

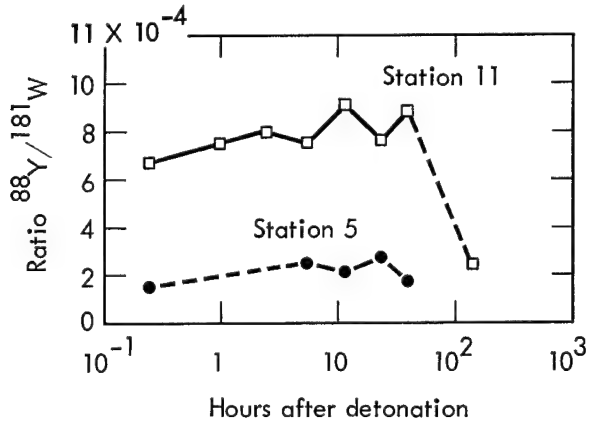

Fig. 21. Ratio of airborne $^{88}Y/^{181}W$ as a function of time at Stations 5 and 11. The other stations responded like Station 11, indicating that some material relatively depleted in ^{88}Y reached only Station 5. The dashed lines indicate portions of the curves for which data were unavailable or contained such high statistical counting errors that they were omitted.

though they had a few high values. The consistently low values for Station 5 indicate that this station was exposed to some material, relatively depleted in ^{88}Y, which did not reach the other stations. Station 5 was somewhat closer to ground zero than any other downwind station.

The ^{132}Te exhibited the most unusual behavior, and the ratio of $^{132}Te/^{181}W$ varied over three orders of magnitude (Fig. 22). Station 5 again exhibited the most unusual behavior, but not in any consistent manner. Station 11 also showed wide variations with time; the three available values for Station T1 indicate that there was no significant fractionation with distance. Of particular interest is the fact that ^{132}Te during one time period at Station 5 was the predominant nuclide, with a concentration 100 times greater than that of ^{181}W.

Figure 23 is a similar plot for $^{140}Ba/^{140}La$ for Stations 5, 11, and T1. This is the only case observed so far in which there is a clear-cut fractionation as a function of distance, with $^{140}Ba/^{140}La$ enriched at the far-out Station T1. All other close-in stations behaved much like Stations 5 and 11.

As the time interval between the event and our germanium lithium-drifted detector analyses increases, many of the shorter-lived isotopes have decayed to negligible levels and can no longer be quantitated. The disappearance of these activities, however, makes it possible to quantitate a number of longer-lived nuclides that were formerly masked. From a brief examination of spectra counted at later times, it appears that the additional identifiable nuclides are ^{54}Mn, ^{95}Zr, ^{110m}Ag, ^{168}Tm, and ^{182}Ta. These

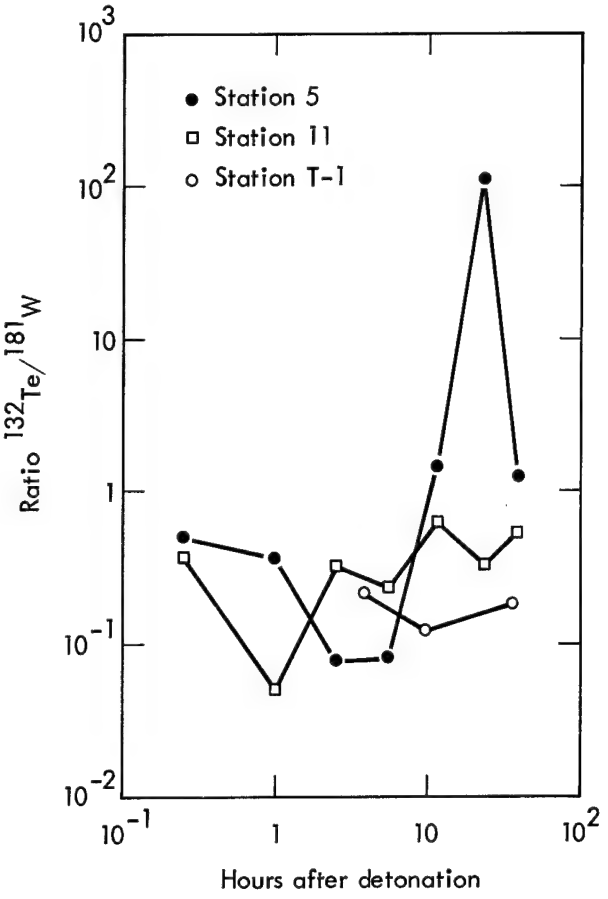

Fig. 22. Ratio of airborne ^{132}Te to ^{181}W as a function of time at Stations 5, 11, T1. The ^{132}Te concentrations exhibited extreme variations.

and any other long-lived gamma-emitting nuclides will be quantitated later and examined for fractionation as functions of time and distance.

SUMMARY AND CONCLUSIONS

1. The air activity at close-in locations remains high for long periods of time after detonation. Secondary peak of air activity are seen as late as 2 to 4 days postshot and amount to as much as 30 percent of the initial activity. Further study is required to determine how these secondary peaks are correlated with far-our activity, since it is not clear that air activity measured 7 ft above the surface is representative of material transported for long distances; however, the air activity seen after the Schooner Event in Arizona, New Mexico, and Texas by the U. S. Public Health Service[12] and in Southern California by the California Department of Public Health[13] indicates that large-scale secondary redistribution does occur. Therefore, models that consider a single cloud moving under constraints operating

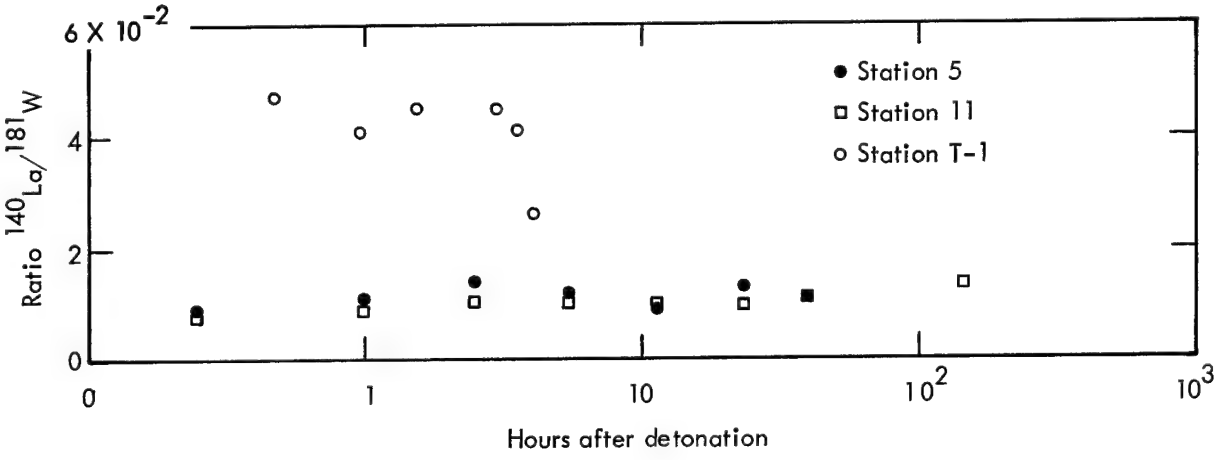

Fig. 23. Ratio of airborne $^{140}La/^{181}W$ as a function of time at Stations 5, 11, and T1. The ^{140}La was the only isotope that showed a clearcut fractionation as a function of distance.

at shot-time may fail to predict significant biological hazards in populated areas which are not in the initial fallout zone.

For the next cratering events, which are planned to be large compared to past events, it would be desirable to add more monitoring stations not in the initial fallout field and to operate more distant stations over longer time periods. Also, to assess more fully the dynamic situation as it exists in the fallout field, we would like to use automatic fallout trays and downward-looking ion chambers to assay simultaneously what is on the ground and what is in the air as functions of time. This would enable us to calculate resuspension factors, which would be of interest to a variety of nuclear programs concerned with the resuspension of particulate debris.

2. Very high off-site activities were recorded after the Schooner Event. The air-activity data recorded at Station T1 are summarized in Table 4 in terms of the ICRP maximum permissible concentration (MPC) values for continuous exposure[9]; this should place these values in their appropriate biological perspective. As can be seen, the isotopes of tungsten represented the principal hazard, and the levels of ^{187}W exceeded the MPC values by a factor of five. Averaged over the total sampling time, however, the level was about equal to the MPC value. Air activity levels at Queen City Summit were probably about 10 times these. In terms of evaluating long-term hazards, the deposition on the ground is of more concern. The finding of activities as high as 1 mCi/m^2 has led us to initiate ecological studies in this area to determine in situ the biological availability and any possible trophic-level concentration factors.

Table 4. Peak air activity at Station T1 compared to (Maximum Permissible Air Concentration) (MPC) for continuous exposure of occupational workers.

Nuclide	Peak activity (pCi/m^3)	MPC (pCi/m^3)	Peak activity (% of MPC)
^{74}As	4.0×10^1	4×10^4	
^{103}Ru	2.9×10^1	3×10^4	
^{131}I	1.1×10^2	3×10^3	3.7
^{132}Te	7.4×10^2	4×10^4	1.8
$^{140}Ba/^{140}La$	2.5×10^2	1×10^4	2.5
^{141}Ce	3.8	5×10^4	
^{181}W	6.1×10^3	4×10^4	15
^{187}W	4.9×10^5	1×10^5	490
^{196}Au	2.2×10^2	2×10^5	

3. While the above studies are of interest of and by themselves, it is apparent that a complete evaluation of the long-term biological hazards needs to consider deposition at more remote locations and to integrate studies in areas of significant agricultural activity. In another part of this study, not discussed here, we made a few measurements of deposition in Utah and Idaho, and found levels of ^{181}W as high as 14,000 pCi/m^2 in Cache Valley, Utah—360 miles from ground zero.[14] The presence of such levels in areas of significant dairy farming activity indicates the desirablility of performing additional studies at such locations. Thus, we would like to expand our program to Utah, where we would measure air activity, ground deposition, and transport through the ecological chain. The latter would be determined by sampling soil, grass, feed, milk, animal organs and bones, and also human organs if available. By so doing we believe we

could achieve a comprehensive study of the relationships between air activity, ground deposition, and ecological transport in situations appropriate to assessing the biological hazards of cratering events.

Surface-Atmospheric Debris Separator and Collector (Sadsac): Design and Operation

Bruce R. Clegg and John C. Taylor

INTRODUCTION

Nuclear cratering tests produce airborne radionuclides whose surface deposition patterns depend on particle size. Animal feeding experiments require large amounts of such debris that has been size-fractionated. To obtain sufficient quantities of such size-fractionated debris, we designed a high-volume air-sampler to collect size fractions roughly equivalent to local, near, and far-out ground deposition.

COLLECTOR DESIGN

The engineering design was dictated by the need for high air-flow rate and by the availability of standard industrial components. The collector unit (Fig. 24) includes a settling box, a cyclone separator, a filter, and a fan-engine.

The design of the settling box assumes Stokes' Law, i.e., free fall velocity through air for an assumed average particle density of 2. Assuming laminar flow, the flow velocity should decrease to zero at the sides of the box; hence, the particles will be largest in the center (~150 μ), decreasing outward to near zero. This rough separation functions mainly to keep large rocks out of the cyclone separator. The settling unit was designed so that the entire 12-ft unit could be assembled with only four bolts.

The return-flow cyclone removes particles down to 10 μ by means of inertial separation. The particles in the entering air are centrifuged down the outer walls (which are modified by scrolls and cones) into a bin, while the cleaner air concentrates near the top axis for removal to the filter. The design necessitates compromises in cyclone size, power input, mass efficiency, and particle cutoff size. A standard agricultural cyclone separator was designed on the basis of tests of similar units.[15] When measurements were scaled for 4000 ft^3/min at a pressure drop of 4 in. of water, the collection efficiency was calculated to be 80 percent for the 10-μ particle fraction, assuming an average particle density of 2. A small agricultural implements company (Ripon Manufacturing Company) fabricated two units for us.

The unknown proportion of <10-μ particulates encouraged a conservative filter design. Four parallel high-efficiency units (American Air Filter Company, referred to as CWS-6 and AEC-1) presented about 1200 ft^2 area, with an unloaded pressure drop of 1 in. at 4000 ft^3/min. The filters are rated not to exceed 0.05 percent penetration at 1 in. by the DOP (dioctyl phthalate) penetration test.[16]

An industrial exhaust fan supplies 4000 ft^3/min at 6 in. of pressure. A 12.5-hp gasoline engine set at 3000 rpm generates about 8.5 hp at the altitude of the NTS site.

It was necessary to provide sufficient fuel for 60 hr of operation, to permit

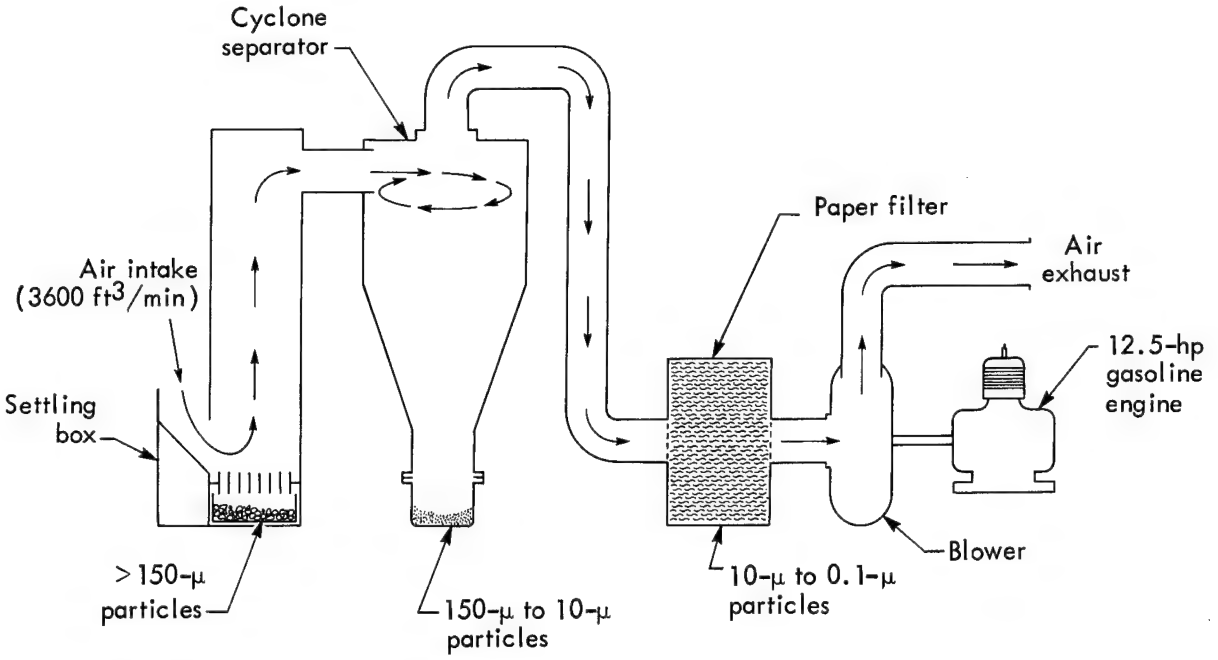

Fig. 24. Schematic diagram of the high-volume collector and separator for airborne debris.

manual startup 12 hr before detonation, with sufficient time to cover the desired sampling period. Automatic starting of this engine in cold weather was considered too marginal. Final testing of the assembled units showed an air-flow of 3600 ft^3/min throughout with a pressure drop of 4.5 in. in the cyclone and 1- to 2-in. in the filters, and a ducting pressure drop of about 1/2 inch.

RESULTS

On 20 December 1968 the middle cyclone fraction, the large settling-box fractions, and small samples of both filters were recovered. Both collector units apparently functioned during the test, and neither sustained a direct hit, but a 2- to 3-ft crater several feet away from Unit No. 2 suggested that this was merely luck.

The cyclones contained 600 and 1100 g, respectively, of dry, gray powder. This material was used for animal feeding experiments. The settling-box fractions, however, contained mostly water from postshot rainfall, rocks, and some fine powder similar to that in the cyclones. Partial destruction of the collecting containers for the settling box prevented accurate measurements of their weight.

The filter material was the most disappointing, however; it unexpectedly proved to contain too much inorganic material for ashing and subsequent analysis or for animal feeding experiments.

PARTICLE ANALYSIS

Particle analyses of samples from the settling boxes and the cyclones were done by Heft and Steele, whose procedure[17] measures the Stokes' Law velocity in a fluid. This analysis yields a weighed sample in each particle-size category. Considerable uncertainty exists as to the

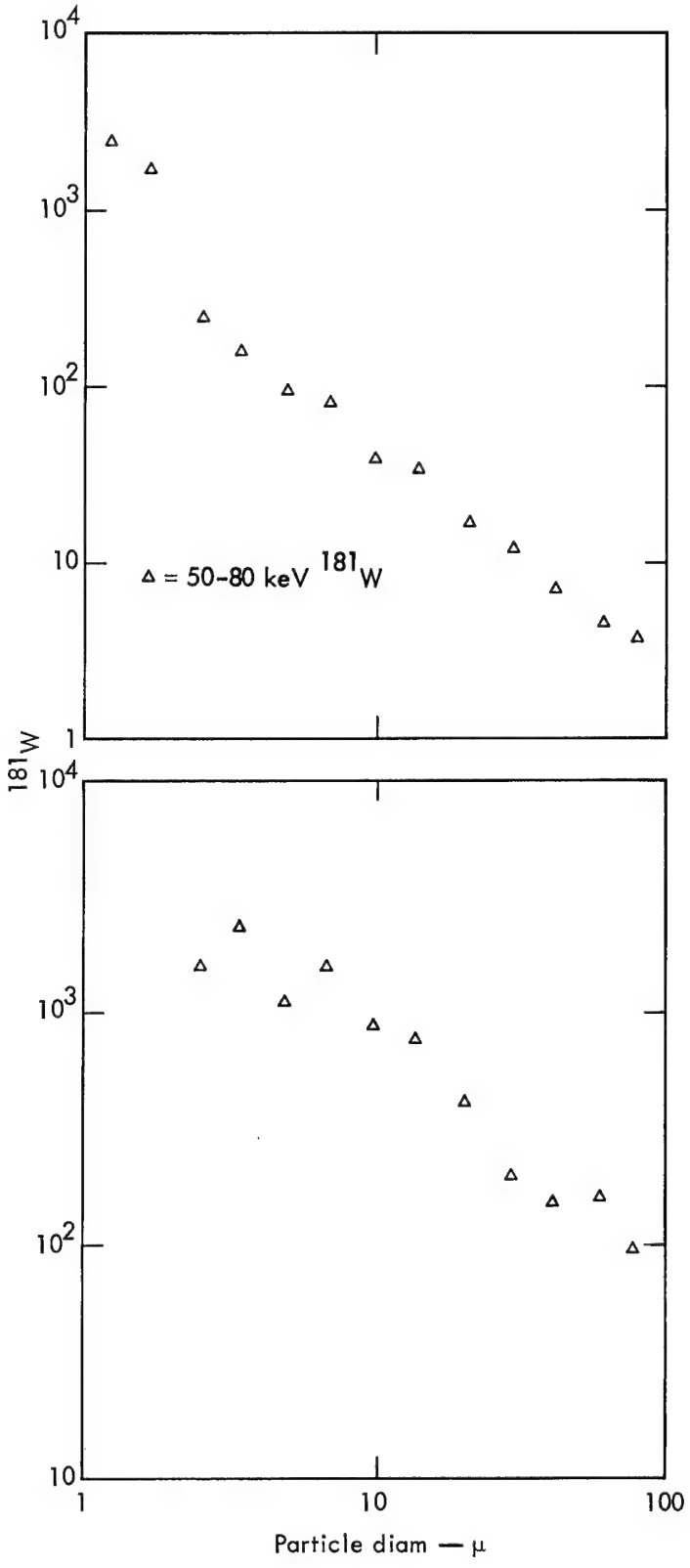

Fig.25. Specific gamma activity (relative activity in counts/min/mg) as a function of particle size for a sample of material collected in the settling box (upper) and for a sample collected in the cyclone separator (lower).

size of the 3-μ fraction, because of the small amount of material collected.

Gamma activity as a function of particle size (Fig. 25) exhibits a straight-line (log-log) plot for sizes > 3 μ. The line represents

$$\gamma = kD\beta,$$

where γ is the activity in counts/min/mg, D is the calculated particle diameter, and β is a constant equal to -0.662 and -0.728 for the two settling boxes and to -0.850 and -0.732 for the two cyclones. If the radionuclides are surface-deposited on existing particles, then

$$d\gamma = \frac{kS\ dD}{m},$$

where m is particle size, S is particle surface area, and (assuming spherical particles and constant mass density),

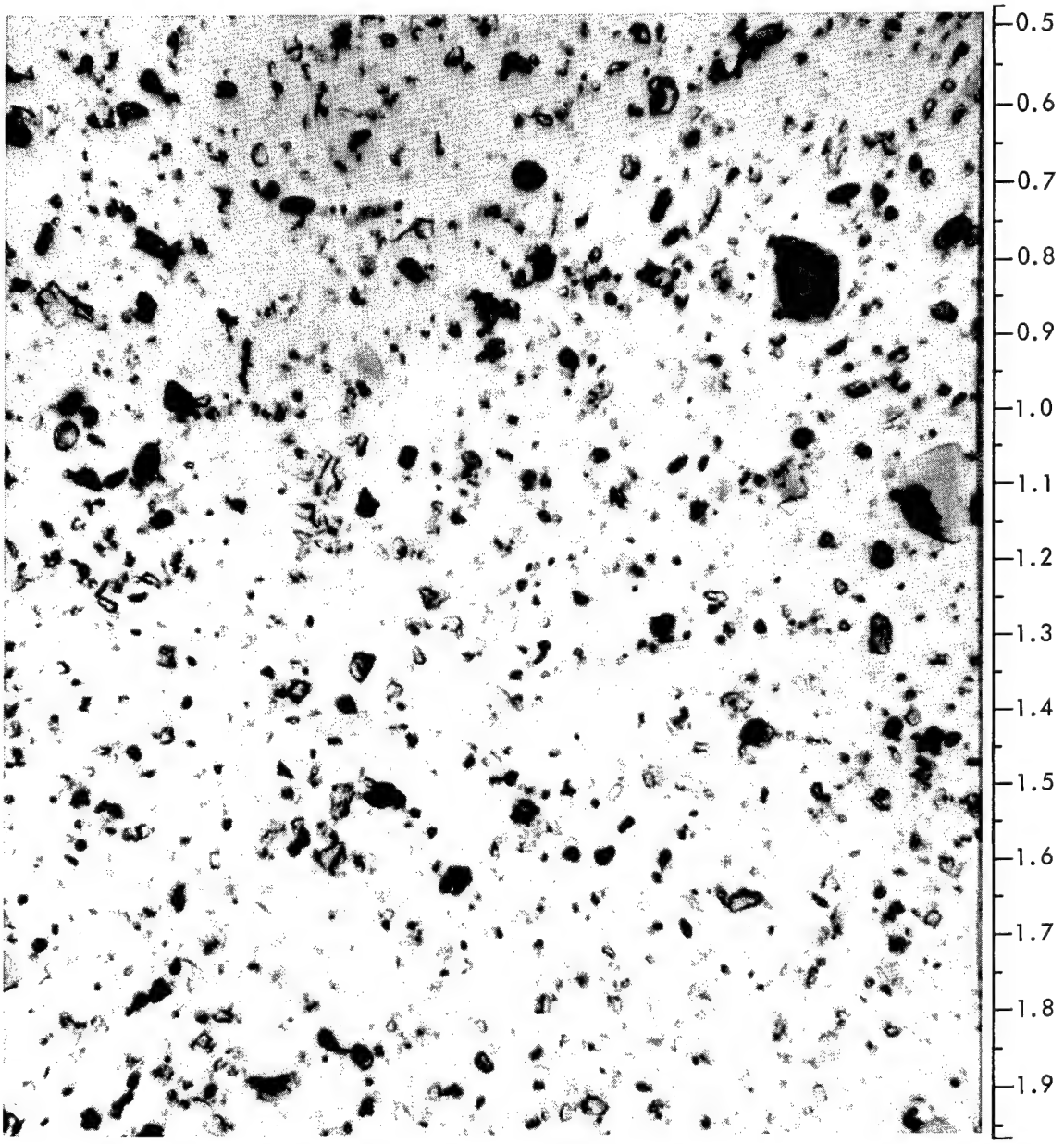

Fig. 26. Photomicrograph of a sample of material collected in the cyclone separator. The dimensions are in millimeters.

$$d\gamma/dD = 6k\pi D^2/\rho\pi D^3 = k'D^{-1}.$$

Therefore, the experimental slope should be -1 for surface deposition and zero for volume distribution. The actually jagged and decidedly nonspherical shape of the particles (Fig. 26) may account for this discrepancy. Equivalent diameters allow calculations of atmospheric fallout time; the jagged structure, however, may result in underestimation of particle volume.

The size distributions of the particle populations from the settling boxes and cyclones (Fig. 27) assume constant mass density throughout the size range. For the settling box (laminar flow), 80 percent of the total particle mass was > 88 μ; the box passes a significant number of particles down to 10 μ. The cyclone population exhibits a drop above 70 μ, induced by the operation of the settling box, with only 1.2 percent of the mass with diameters > 88 μ. The estimated 150-μ cutoff for the settling box was conservative. These population distributions indicate the extent of particle-size fractionation by the settling box and the cyclone.

SPECTRAL ANALYSIS

Samples of the three size fractions have been analyzed by high-resolution, solid-state (GeLi) spectroscopy,[18] but interpretation of the data is not yet complete. The refractory materials (such as

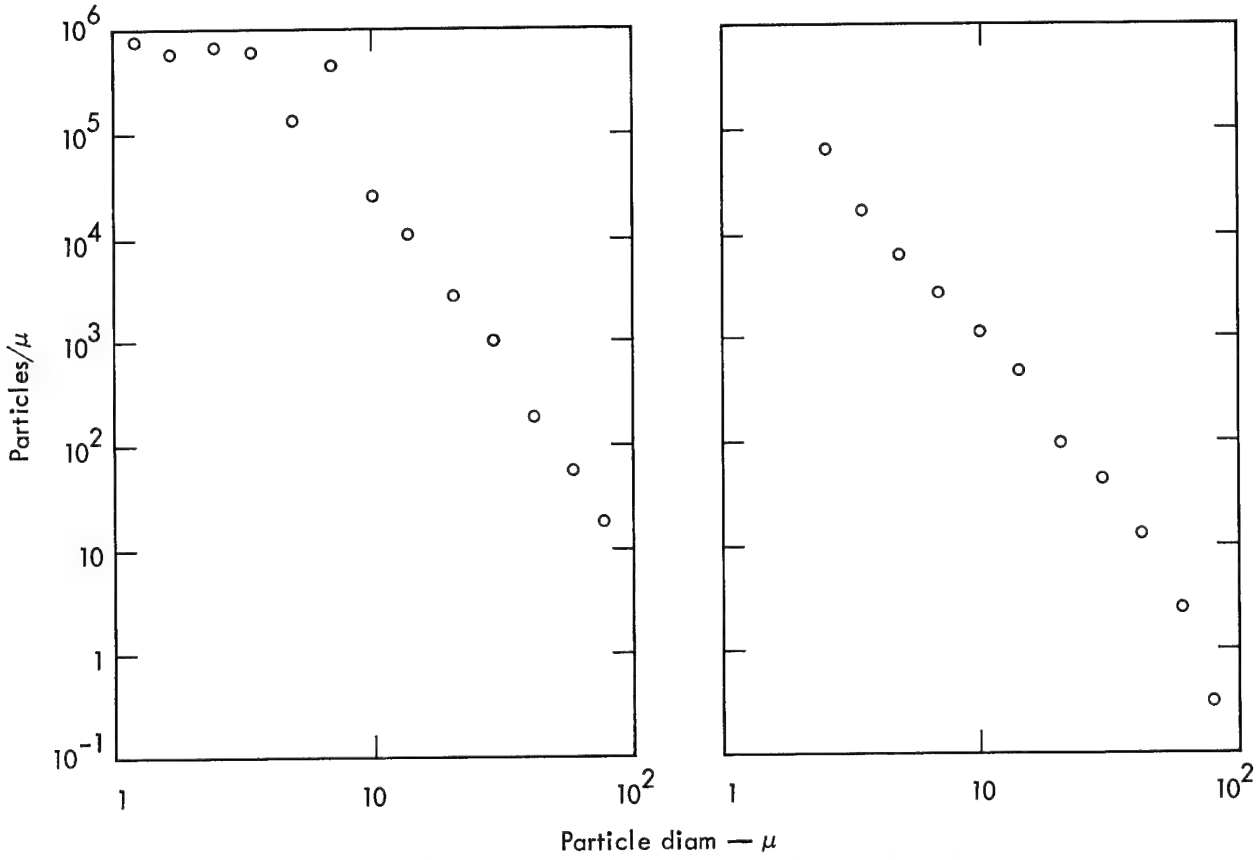

Fig. 27. Particle population distribution as a function of particle size for a sample collected in the settling box (left), and for a sample collected in the cyclone separator (right).

^{181}W, ^{54}Mn, and ^{60}Co) exhibit little or no fractionation, whereas the volatile materials (^{137}Cs and ^{140}Ba) are fractionated to five to ten times the expected concentration in the filter unit. The gaseous precursors of these volatiles produce submicron particles which only the filter unit captures.

SUMMARY AND CONCLUSIONS

Both debris collectors functioned approximately to design estimates. However, the smallest and possibly the most important fraction was unusable in animal feeding experiments, because of the presence of unashable filter medium.

Experience suggests many improvements for future designs, including compact packaging, omission of the settling box, provision for rapid removal of samples, improved air-flow instrumentation, and start-and-stop control. The question remains whether special cellulose filters or electronic precipitation should be used to collect the small particle-size fractions.

Studies on Radionuclide and Mass Partitioning According to Particle Size and Class

Robert E. Heft, William A. Steele, and
William A. Phillips

INTRODUCTION

The radionuclides produced by a nuclear detonation are distributed in the biosphere in a manner which varies from isotope to isotope and from detonation to detonation. Partitioning of the radioisotopes produced by cratering detonations follows a pattern that can be understood in terms of a three-stage condensation process.

1. The first stage of condensation is in the underground cavity produced by the detonation. Refractory radioisotopes, those whose boiling points are much higher than the melting temperature of the environmental soil, are quantitatively scavenged by the molten material that lines the cavity. Other radioisotopes are only partially scavenged during this stage. In the subsequent explosion the molten cavity-liner breaks up into particles that constitute a distinctive class and that will be referred to here as slag particles. Both radioisotopic composition and specific isotopic abundance in this particle class are relatively independent of particle size. This indicates that the radionuclides in these particles are volume-distributed and therefore that their availability depends on the solubility of the particles themselves. The time scale of this condensation stage is of the order of a second for a typical cratering detonation.

2. The second stage of condensation occurs during the passage of the cavity gas through the strongly shocked and crushed overlying rock or soil, up to the time of venting. During this stage, radioisotopes of intermediate volatility complete their condensation. However, since this soil material is crushed but not melted, the radionuclides are surface-deposited rather than volume-deposited, and hence, may be more readily leached than those nuclides carried by slag particles. The radioactive particles formed during this process are for the most part separated from the remaining radioactive plasma at the time of venting and fall to the side to form the crater lip. This particle class will be referred here to as lateral ejecta. The time scale of this second stage of condensation is of the order of a few seconds.

3. The third stage of condensation occurs after venting. Only a small fraction of the crushed soil through which the radioactive gas has moved remains with the gas after venting occurs. Therefore, the highly volatile radioactive species are found to be significantly enriched in this fraction. The volatility of the individual radionuclides may be inherent, as in the case of gold or arsenic isotopes, or it may be due to the isotope's having a rare gas precursor, as in the case of fission-product strontium or cesium. The time scale for this stage is of the order of a few minutes to perhaps 20 min. In the case of land-surface cratering, the

condensation is on nonmolten particles and thus the radionuclides are again surface-deposited. Soil particles in this class will be referred to here as vertical ejecta.

The process of radionuclide condensation is essentially complete within 20 min following detonation. At this time in a terrestrial cratering detonation, the radionuclide population is completely accounted for by two main components:

1. An aerial cloud, which consists of vertical ejecta plus a small fraction of the radioactive slag particles.
2. The base surge and crater wall, which consist of lateral ejecta plus most of the radioactive slag particles.

Samples of particulate radioactive debris taken in the aerial cloud at various times and locations may exhibit markedly different radioisotopic compositions. However, almost all the variation can be accounted for by the variation between samples in the ratio of slag particles to vertical ejecta particles. Similarly, variation in the radioisotopic composition of samples collected in the base surge or on the crater lip can be accounted for by the variation between samples in the relative amount of slag material. Finally, for either aerial or crater samples, the variation in radioisotopic composition between size-separated fractions from any collection can similarly be explained. The experimental program undertaken for the Schooner experiment is designed to provide data on the radioisotopic composition and specific radionuclide abundance in each of the three components and within each size fraction.

EXPERIMENTAL PROGRAM

Slag particles are likely to exhibit an unusual appearance, low density, relatively large size. Thus, it is quite feasible to select slag specimens from mixed particle collections. By analyzing a number of these we can determine radioisotopic composition and radionuclide abundance data that apply to the slag component. These data may be used to correct for the slag contribution to the particle mixtures normally found in aerial or crater-lip samples and thus to arrive at composition and abundance values for the vertical and lateral ejecta.

To this end a number of samples are subjected to extensive gamma spectrometric analysis. All gamma spectrometric analyses are performed on high-resolution germanium diode counting systems. The high resolution permits the simultaneous determination of numerous isotopes in a complex spectrum. By extensive analysis we mean recounting of the same sample at intervals, so that as short-lived activities decay out, additional longer-lived gamma activities become resolvable.

For the Schooner Event a total of 24 samples representative of the three major components were put into an extensive analysis program beginning at 5 days after detonation. In addition, a large number of samples are in the process of being analyzed for the more limited number of isotopes determinable from a single spectrum taken several weeks after the

event. These samples consist of size-separated fractions from aerial and tray collections as well as crater profile samples collected over a grid of positions (and where pertinent at various depths) in the Schooner crater lip and fallout field. The data from these samples will be used to determine how individual radionuclides are partitioned as a function of particle size and sample location.

Summary of Parachute-Borne Air Sampling Program on Schooner

Jerry J. Cohen*

The purpose of this project, under the joint auspices of the Division of Peaceful Nuclear Explosives and the Division of Biology and Medicine, U. S. Atomic Energy Commission was to determine the quantity and the properties of the radioactivity released from a nuclear cratering event. Specific objectives were:

1. To determine the total quantities of various airborne particulate radioactive species in the cloud.
2. To determine the relative distributions of the radioactivity in the cloud, with altitude, from side to side, and from front to rear.
3. To determine the shape and dimensions of the radioactive cloud as well as its volume.
4. To determine the inertial characteristics of the airborne radioactivity.

To accomplish the above objectives, a total of 314 parachute-borne air samplers were dropped through the cloud from five C-130 aircraft. The drops occurred during two separate overflights at H + 30 min and H + 1 hr. Three hundred of the drop-packages were small integrating samplers collecting particulate debris on a glass-fiber filter at a rate of 0.5 m^3/min. The remainder consisted of sequential samplers designed to determine relative concentrations with altitude and cascade impactors for particle-size analysis. The equipment is pictured in Fig. 28. The aircraft formation overflying the cloud at H + 30 min is shown in Fig. 29.

Two hundred and sixty of the samplers were successfully recovered and analyzed within 1 month after detonation. The analysis permitted construction of the cloud

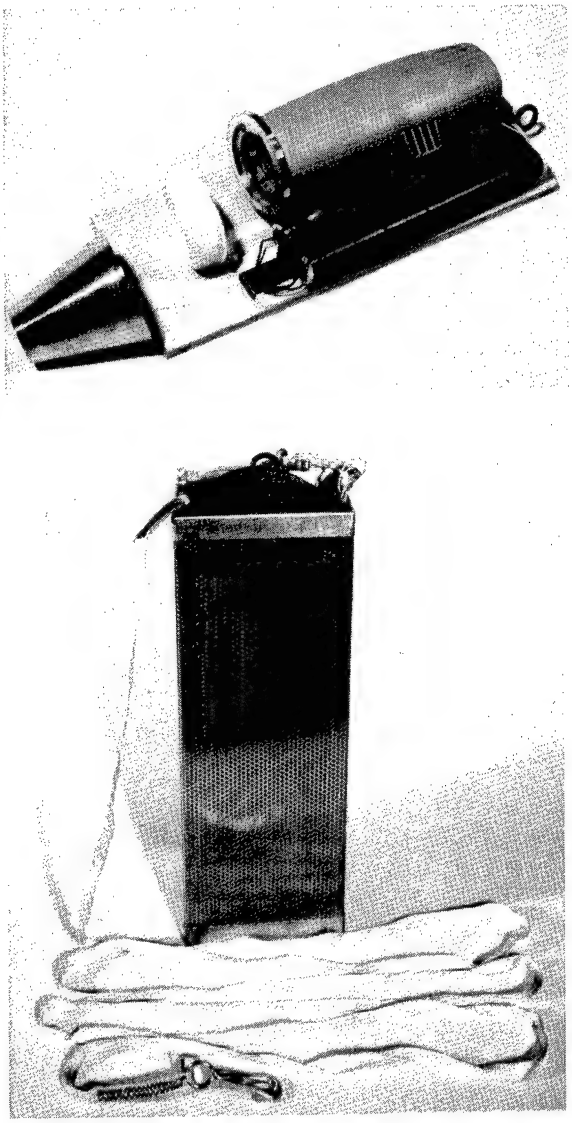

Fig. 28. The parachute-borne integrating air-sampler. Upper, partially disassembled. Lower, assembled.

*Plowshare Division, LRL, Livermore.

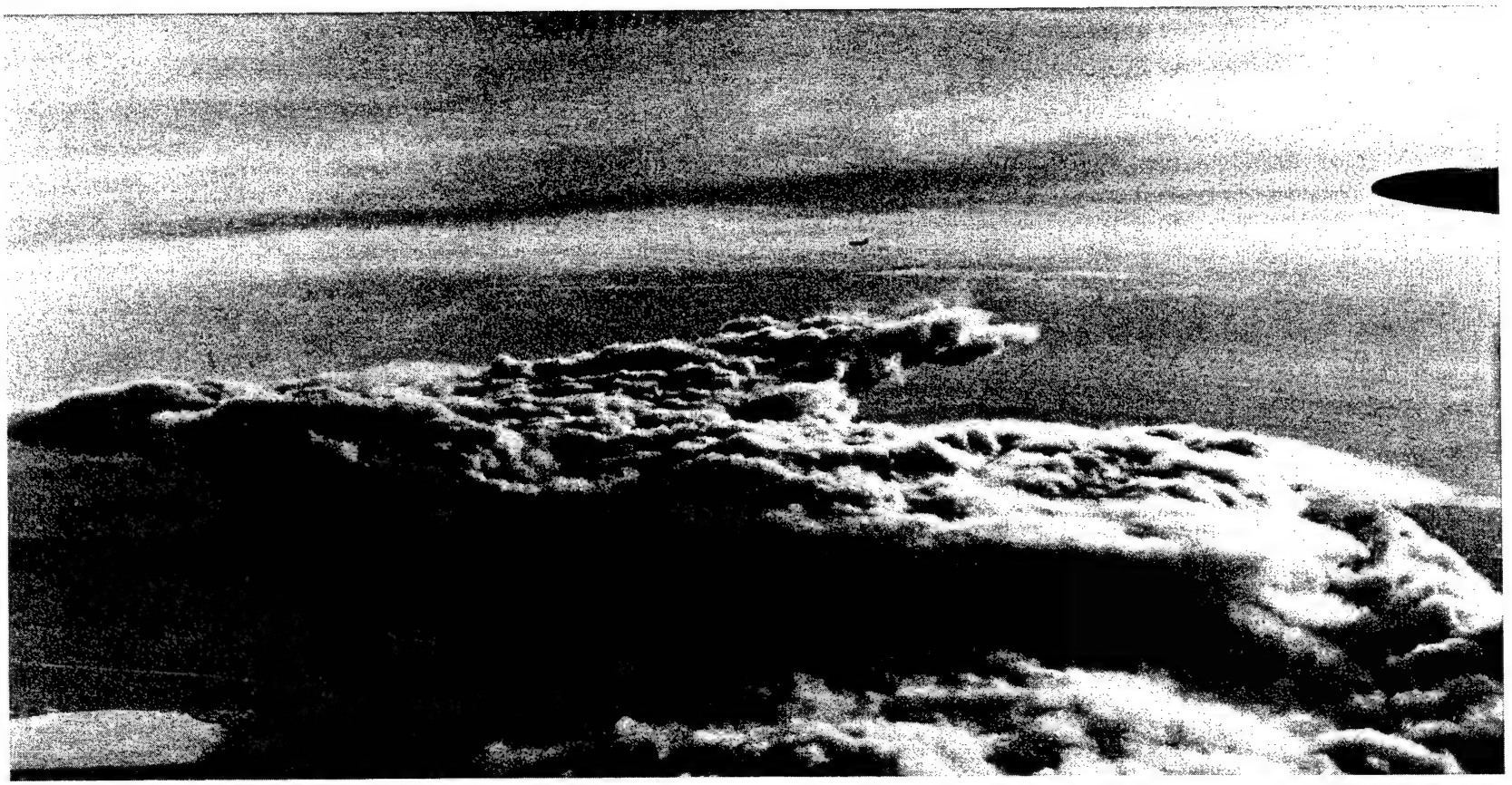

Fig. 29. Aircraft overflying the Schooner cloud at H + 30 min.

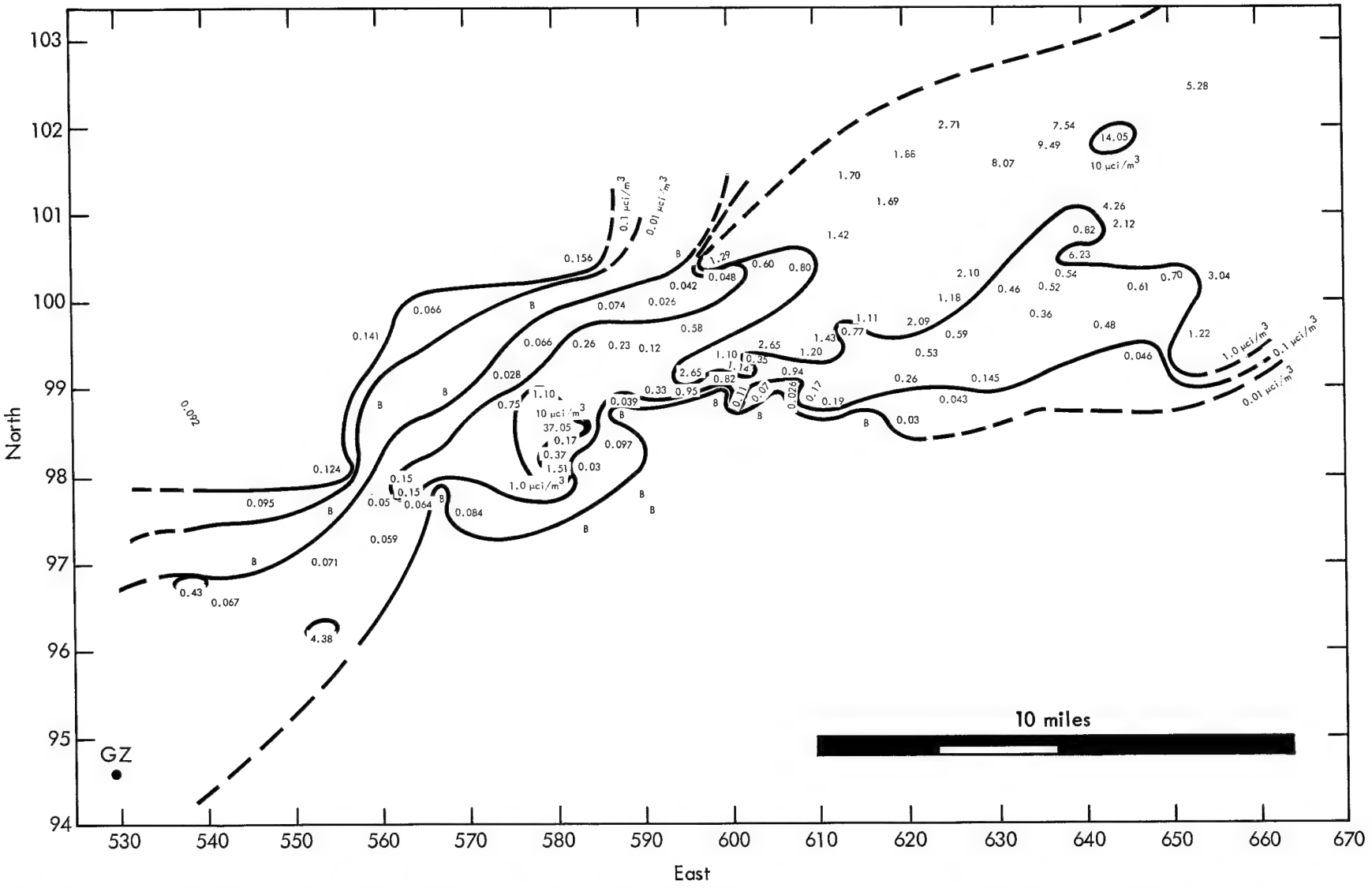

Fig. 30. The Schooner cloud contour based on measurements made at H + 1 hr. The isopleths are based on the concentration of gross activity at H + 50 hr integrated from 18,500 ft MSL to the terrain surface. The coordinates are based on the Central Nevada Grid Coordinate system and the unit is 10,000 ft. The dashed-line contours are based on extrapolated data. B = background reading.

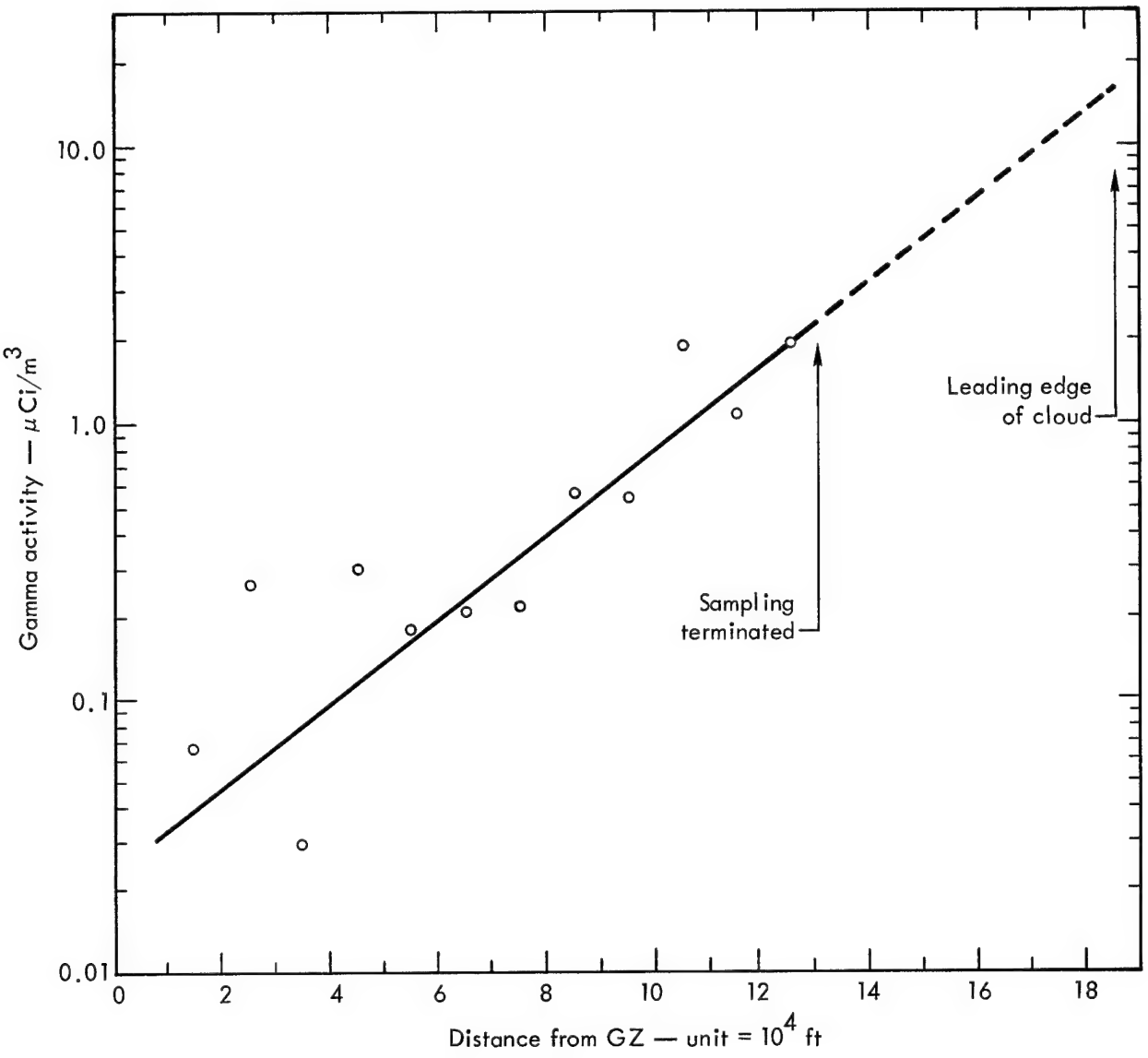

Fig. 31. Mean gross gamma activity of the main cloud vs distance from GZ at H + 1 hr.

contour outline. The H + 1 hr cloud contour is shown in Fig. 30. (The isopleths are based on concentration of gross activity at H + 50 hr integrated from 18,500 ft MSL to the terrain surface.)

To determine total cloud burdens for various nuclides it was necessary to extrapolate data, since it was not possible to completely cover the cloud on either overflight. The extrapolation was accomplished by plotting the 1-hr cloud concentrations against distance from GZ out to 130,000 ft, the point at which the overpass was terminated (Fig. 31). According to aerial photos the leading edge of the cloud at H + 1 hr was about 185,000 ft from GZ. By assuming a constant rate of increase in concentration out to the leading edge, and using cloud volumes based on aerial photography, 1-hr total cloud burdens were calculated. These calculations yield maximum results,

since it is believed that increasing concentration all the way to the leading edge is improbable. One can calculate minimum cloud burdens by assuming no radioactivity beyond the sampling terminus. According to this analysis for the nuclide ^{181}W at H + 1 hr, the minimum cloud burden was 2.5×10^5 Ci, and the maximum would be 1.0×10^6 Ci.

A complete report of this study is to be published in the near future.[19]

Radioecological Studies

John J. Koranda, John R. Martin,
Robert W. Wikkerink, and Marshall L. Stuart

INTRODUCTION

The objectives of this study were as follows:

1. To measure tritium concentrations in the base-surge cloud as it passed over a series of air-samplers deployed at 3000 ft from GZ between 30° W of N and approximately 175° E of N.
2. To measure tritium concentrations on fallout particles collected in fallout trays as far as possible from GZ. Special provisions were made to collect fallout-tray material in glass tubes that could be attached directly to a vacuum system.
3. To measure tritium concentrations in the bulk and missile ejecta deposited around the crater at an early time, for comparison with a more extensive sampling program to be conducted when the radiation field permitted longer work periods.
4. To measure the concentrations and distributions of gamma-emitting radionuclides in the bulk and close-in missile ejecta at an early time for comparison with subsequent studies of radionuclide redistribution from the ejecta materials.

This research is part of the general program of studies concerned with the distribution and movement of radionuclides from nuclear crater ejecta which have been conducted at Sedan and will be extended to the Schooner crater area.

AIR SAMPLERS

The objectives described in paragraph 1 above were accomplished with the instrumentation shown in Figs. 32 and 33. The essential components were the seismic detector that activated the sampling system, the timing module that determined turn-on time and the duration of the sampling period, the S-2 sampling cartridge containing "Anhydrone"* or $MgClO_4$, the 12-V dc vacuum cleaner blower that pulled air through the filter, and the 12-V dc battery. The S-2 filter cartridge is the same physical assembly used in the aircraft that sampled the cloud at early times.

The water sample is recovered from the Anhydrone material by essentially the same procedure as used by the Radiochemistry Department of LRL. The Anhydrone is placed in a long Pyrex tube connected via glass to a cold trap (CO_2). A small electric tube furnace is placed around the tube and a temperature of 200° C is maintained as the THO is sublimed from the Anhydrone. Tritium concentrations are determined by liquid scintillation counting.

During the Schooner Event, portions of the tritium-sampling instrumentation were destroyed by large rock missiles deposited in the 3000- to 4000-ft arc from GZ. Only one of the Anhydrone cartridges received a direct hit; the

*The Anydrone powder is dried in a vacuum oven before use.

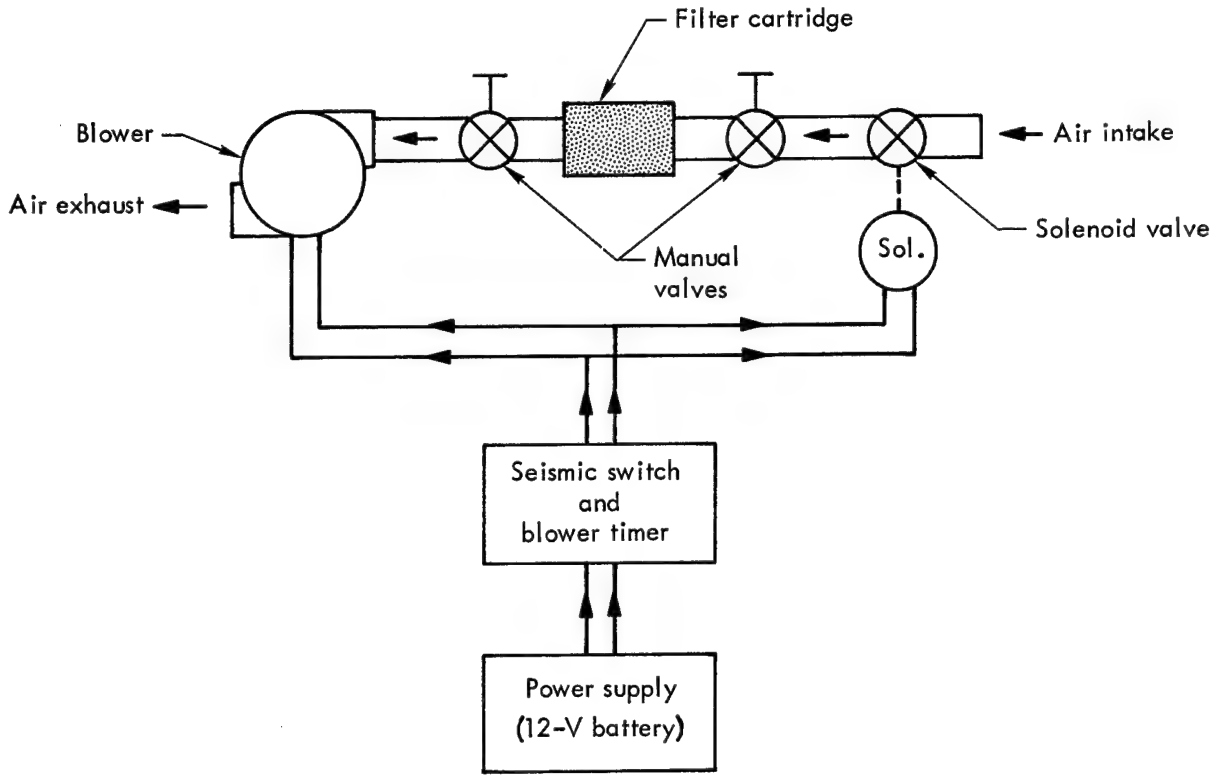

Fig. 32. Diagram of tritium air-sampler. The filter cartridge holds anhydrous magnesium perchlorate.

remaining eleven were processed as if they had all functioned as planned. In one case the batteries were buried under a 3-ft-diameter rock while the blower and Anhydrone cartridge remained untouched; apparently the Anhydrone absorbed a small amount of air moisture (usually less than 1 ml of water), and a small sample of the base-surge cloud was obtained in spite of the loss of electrical power. These samplers theoretically continued to absorb air moisture after the event, but for some reason the specific activity of THO in the nonfunctioning samplers was comparable to those which operated as planned. It is our opinion that we could have obtained an adequate sample of base-surge air at 5000 or 6000 ft from GZ without incurring the destruction of the samplers by large rock missiles. Future emplacement of instruments will be based on this useful but destructive experience.

The data obtained from 11 air samplers are shown in Fig. 34 and compared with the data obtained in the actual cloud by aircraft at early times,* using essentially the same sampling equipment as was used on the ground. The ground-based Anhydrone filters contained THO with a specific activity that ranged through two orders of magnitude, which, however, embraced the range of concentrations obtained in the main cloud. The highest concentration obtained in the base-surge cloud by aircraft at 7500 ft was an order of magnitude lower than obtained in the

*Data obtained by Radiochemistry Department, LRL.

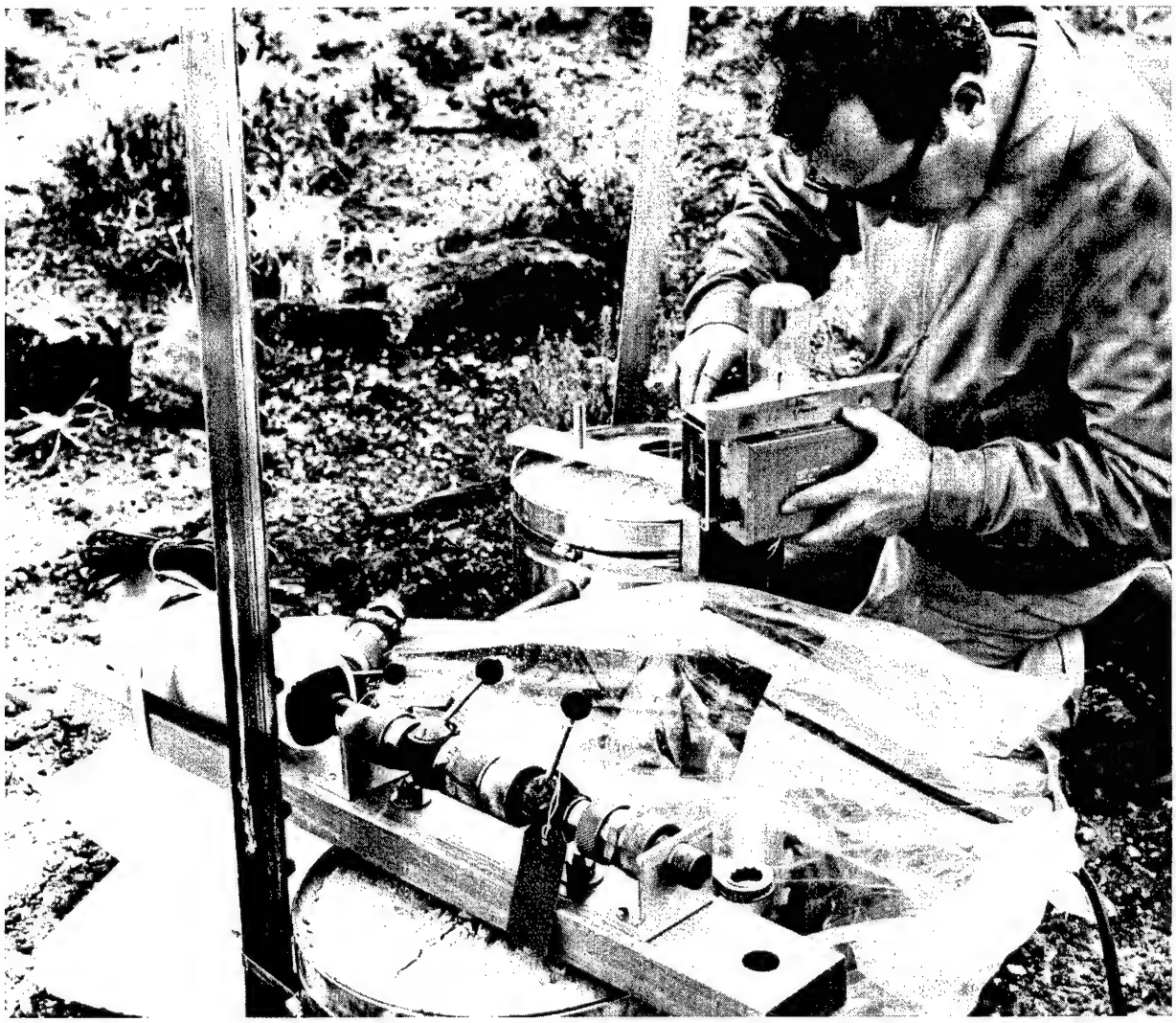

Fig. 33. Installation of a tritium air-sampler in the field.

ground-based air samplers. The dilution of tritium apparent in the main cloud at low elevations above the shot point is no doubt caused by the interaction between the gaseous cloud formed by the detonation and the stable water in the atmosphere during cloud travel. It would seem to be possible to utilize the base-surge cloud concentrations obtained in measurements like those made on the ground in the Schooner Event, together with the photographic measurements of base-surge volume, and thus to obtain a tritium inventory for this component. These possibilities will be explored in future cratering experiments, where more extensive and reliable series of measurements will be made.

FALLOUT TRAY SAMPLES: TRITIUM CONCENTRATIONS

The array of fallout trays emplaced around the Schooner GZ is shown in Fig. 35. These trays were retrieved at times ranging up to 30 days after the detonation. The contents had been subjected to various environmental influences such

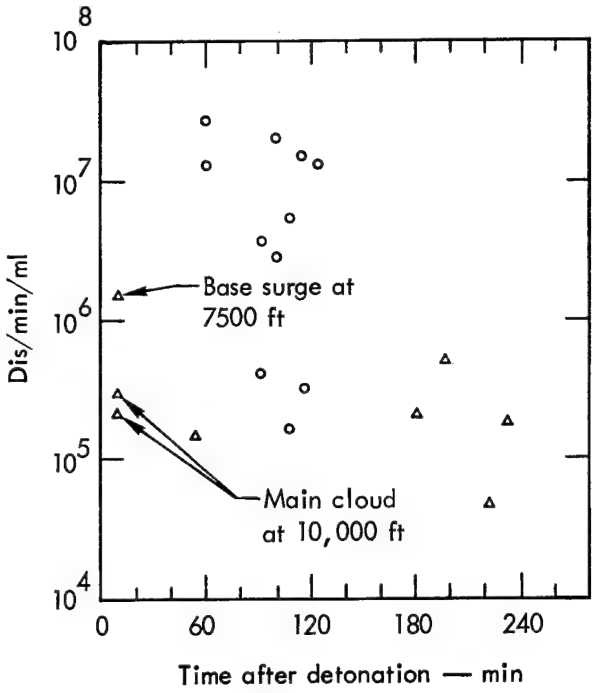

Fig. 34. Tritium specific activities of atmospheric water samples collected at shot-time. Triangles, aircraft Anhydrone filter; circles, ground Anhydrone filter.

as addition of nonradioactive material and redeposition of radioactive particles from the adjacent ground surface, contamination by rainfall or snow, and losses of material by wind movement. In spite of these potential modifying factors, the concentrations of tritium on particles deposited in fallout trays were easily determined as far as 17 miles from GZ. Tritium concentrations on fallout particles (expressed as dis/min per gram of dry material) are shown in Fig. 36. The concentrations in the tray samples obtained at 1000 yards from GZ vary by two orders of magnitude. Undoubtedly this variability was caused in part by the environmental factors described above. For a truly meaningful tritium analysis of fallout particles, a self-opening and self-closing tray should be used to eliminate the strong effect of contamination by precipitation as well as the losses of tritium from the particles by evaporation. Four aliquots of the large particles collected by one of the high-volume particle samplers (Sadsac) placed at 3000 yards from GZ had essentially the same tritium concentrations and agreed well with tray samples collected in the vicinity. The data from the 17-mile trays with concentrations at 10^4 dis/min per gram of dry particles indicate that tritium fallout is a real possibility, because this is in the same activity range as other radionuclides, except the tungsten isotopes which were higher. However, fallout tritium has a high potential for dilution by precipitation.

POSTSHOT AIR TRITIUM CONCENTRATIONS AT THE SCHOONER SITE

In the radioecological studies in progress at Sedan crater, a series of inventory measurements has been made of the

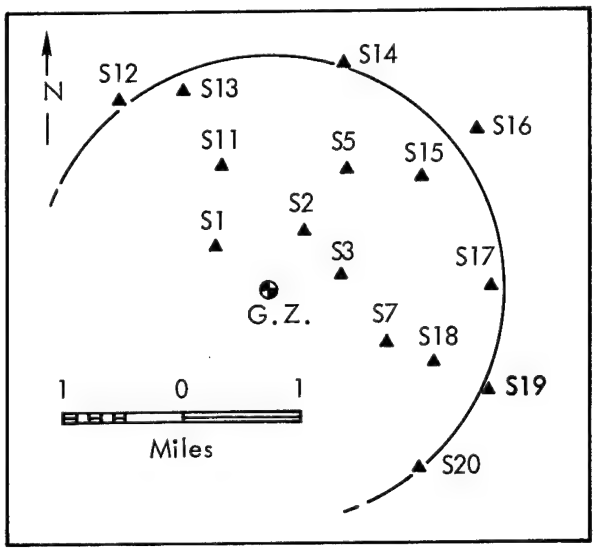

Fig. 35. The array of close-in fallout trays. Three trays were placed at each location. The arc is the 2-mile arc.

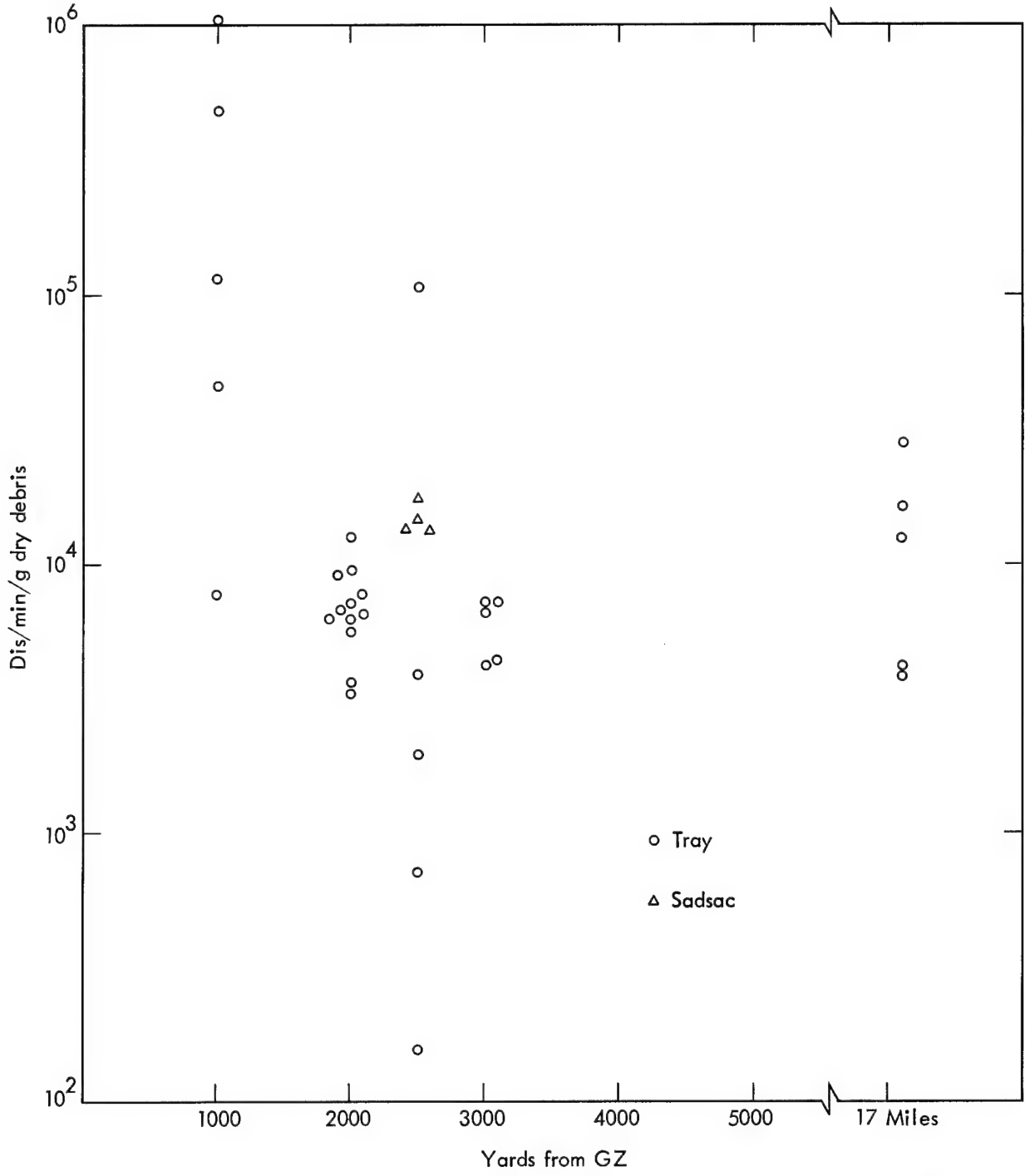

Fig. 36. Tritium concentrations on fallout particles collected in trays from 1000 yards to 17 miles from GZ.

tritium remaining in the ejecta field.[20] The data indicate a mean half-residence time of tritium in Sedan ejecta of 16 ± 3 months. The slope of the line fitted to these inventory measurements when extended to shot-time (T_0) indicated an initial inventory in good agreement with other measurements of residual tritium by Knox et al.[21] It is possible, however, that at early times after the ejecta mass

was deposited onto the ground adjacent to GZ, a rapid off-gassing of water vapor and tritium occurred as the surface layers of ejecta came into equilibrium with the air moving over them. This would give the half-residence-time curve a steep initial slope that would not be detectable if measurements were made after the initial equilibration period. Also, air concentrations of tritium over the ejecta at early times would be elevated.

To determine whether high concentrations of tritium in fact occurred in the air above the Schooner ejecta, on 22-23 January 1969 (46 days postshot) we placed a sequential air-sampling system to sample air at 4 ft above the ground for a period of 15 hr. (The same air samplers were operated at shot-time to draw air through a cartridge of Anhydrone ($MgClO_4$) for a timed period.) An electronic timer module turned each air sampler on and off at the appropriate times. Figure 37 is a plot of the data obtained with this system. The effect of wind in diffusing the local concentration of atmospheric tritium immediately above the ejecta is evident in these data. The calmest period during the time of observation was in the middle of the night; at that time the air concentrations rose by an order of magnitude. To make these measurements properly, we need a certain amount of meterological information: air temperature and humidity as well as local wind variations. We will have the needed instrumentation in future studies of this kind.

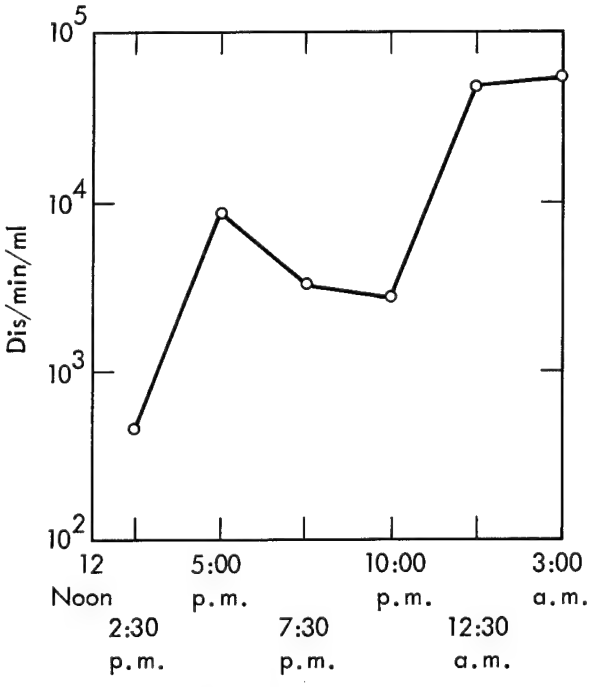

Fig. 37. Diurnal variations in tritium concentrations in the air over Schooner ejecta, 22-23 January 1969.

TRITIUM CONCENTRATIONS IN SHOVEL-SAMPLES OF SURFACE EJECTA, SCHOONER CRATER

On 9 January 1969, personnel of the Bio-Medical Division made a reconnaissance of the Schooner ejecta field to collect an initial series of samples. Because radiation fields up to 1 R/hr were encountered, the work time in the area was limited. Radiation doses received by individuals spending most of the work period in trucks were noticeably lower than in those spending more time on foot. Duplicate shovel samples were obtained along the 3000-ft arc from GZ arc and on the south side of the crater as close as 800 ft from the crater lip. Surface ejecta and the subejecta preshot soil were collected on the 3000 ft arc. At 800 ft and 2000 ft from GZ, surface and depth series to 12 in. were obtained.

The gross radioactivity in the 800-ft samples was reported earlier by Tewes and Koranda.[22] The tritium concentrations in

the shovel samples are given in Fig. 38. Large variation between a given pair of samples is probably caused by variation in the proportion of large particles or rock fragments, which add to the weight of the sample but contribute little to its surface area. It is apparent that tritium concentrations in these samples increase with depth, whereas gross gamma and ^{181}W activities decrease rapidly with depth. The increasing tritium concentrations are the result of precipitation, which elutes the surface tritium into deeper strata of the ejecta.

The depth-varied series of samples obtained at 800 ft from the crater lip showed increased tritium concentrations per gram of dry ejecta to a depth of 1 ft, whereas gamma radioactivities decreased by approximately a factor of 15 in the

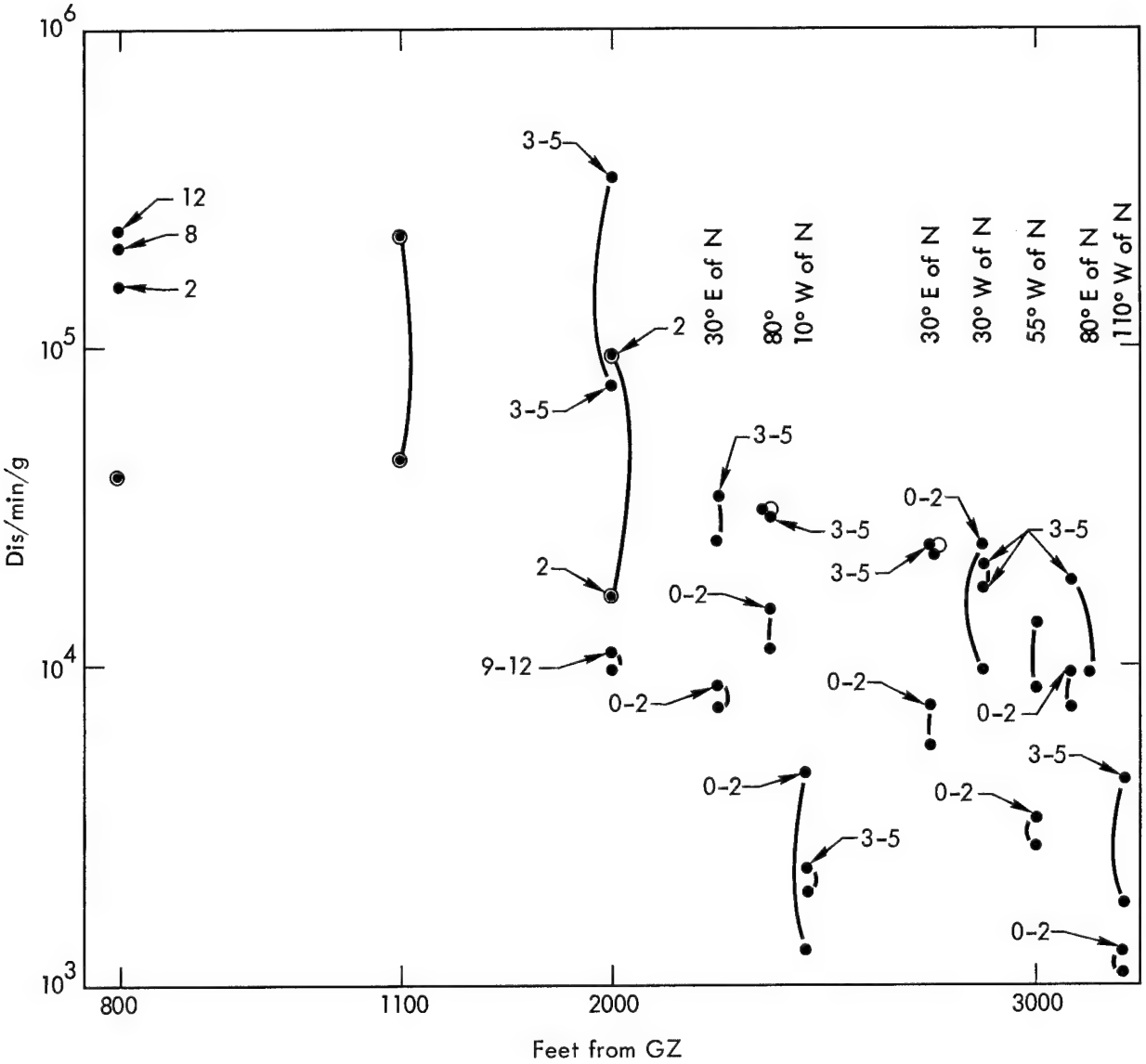

Fig. 38. Tritium concentrations in surface crater ejecta. The curved lines connect duplicate samples taken at the same site. Circled points represent surface samples. Numbers associated with points give the depths (inches) at which subsurface samples were taken.

same sample profile. Based on data obtained from other crater ejecta studies, it is expected that the tritium concentration in the Schooner ejecta will increase with depth until a peak is reached, probably within 3 ft of the surface at these early times, and then decrease rapidly at greater depths in the ejecta mass. The concentrations of tritium in the surface ejecta decrease by an order of magnitude as one moves from the crater lip to a distance of 3000 ft from GZ. This slope of concentration with distance from the crater has also been observed in studies of other crater ejecta fields; no doubt it is produced by the losses incurred as ejecta are transported greater distances from the crater source.

TRITIUM IN LOCAL MAMMALS LIVING AT THE EDGE OF THE SCHOONER EJECTA FIELD

Previously it was shown that crater ejecta at 3000 ft from GZ had concentrations of tritium ranging from 10^3 to $> 10^4$ dis/min per gram. When expressed on the basis of dis/min per ml of soil water, these concentrations ranged from 10^5 to almost 10^6 dis/min per ml in the soil beneath the ejecta layer. The ejecta at this distance varied in depth from 2 to 5 inches. Tritium as THO apparently was eluted from this shallow layer of the ejecta into the subejecta preshot soil, which contained the burrows of many small rodents. The concentrations of tritium in the body water of small rodents captured at 3000 ft from GZ on the south edge of the Schooner ejecta are shown in Fig. 39. On the same graph, tritium concentrations in the soil water are also shown. It is apparent that during the short period between 8 December 1968 (date of detonation) and 18 January 1969, the body water of these animals had almost equilibrated with the soil water.

These small rodents acquired their body water tritium principally by inspiration. The body water tritium concentrations of

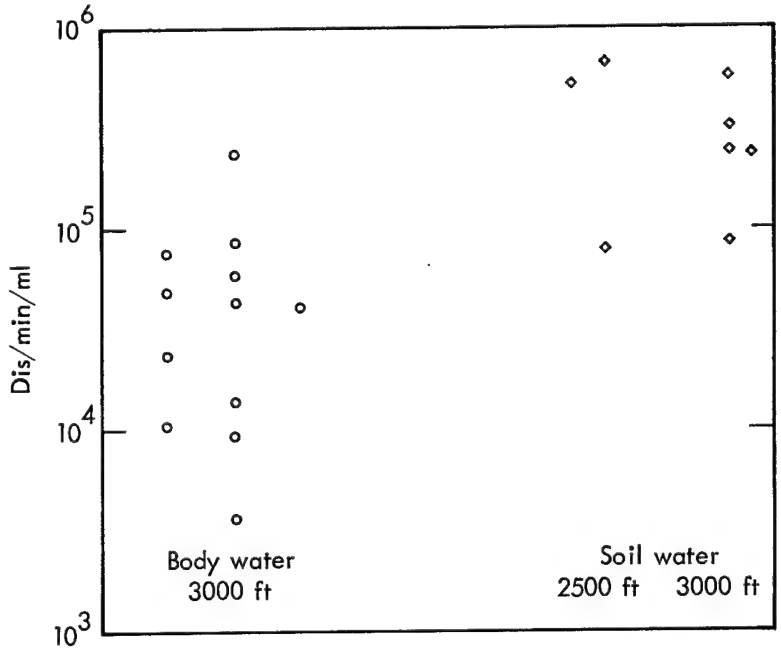

Fig. 39. Tritium concentrations in the body water of small mammals and in the interstitial soil water at 2500 to 3000 ft from GZ.

two samples of animals collected at early times are shown in Fig. 40. It is apparent that the modal values of these samples differ by about an order of magnitude. The most obvious explanation available at this time is that soil-water concentrations of tritium were becoming diluted by incoming precipitation, which was high during this period. The U. S. Weather Bureau data obtained at the NTS Pahute Mesa Station No. 1 indicate that over 8.5 in. of rain fell during the period between December 1968 and April 1969.

Continuing radioecological studies in the Schooner area will attempt to describe the behavior of residual tritium and other long-lived radionuclides in the Schooner postshot environment.

^{181}W IN SCHOONER EJECTA

After their tritium had been extracted, the samples obtained on 9 January 1969 were subjected to gamma analysis. At this time only the ^{181}W data are reported. A depth-varied series of samples was obtained at 800 and at 1465 ft from the crater lip. Their ^{181}W concentrations are given in Table 5. Duplicate analyses of separate aliquots are shown for the samples taken at 1465 ft from the crater.

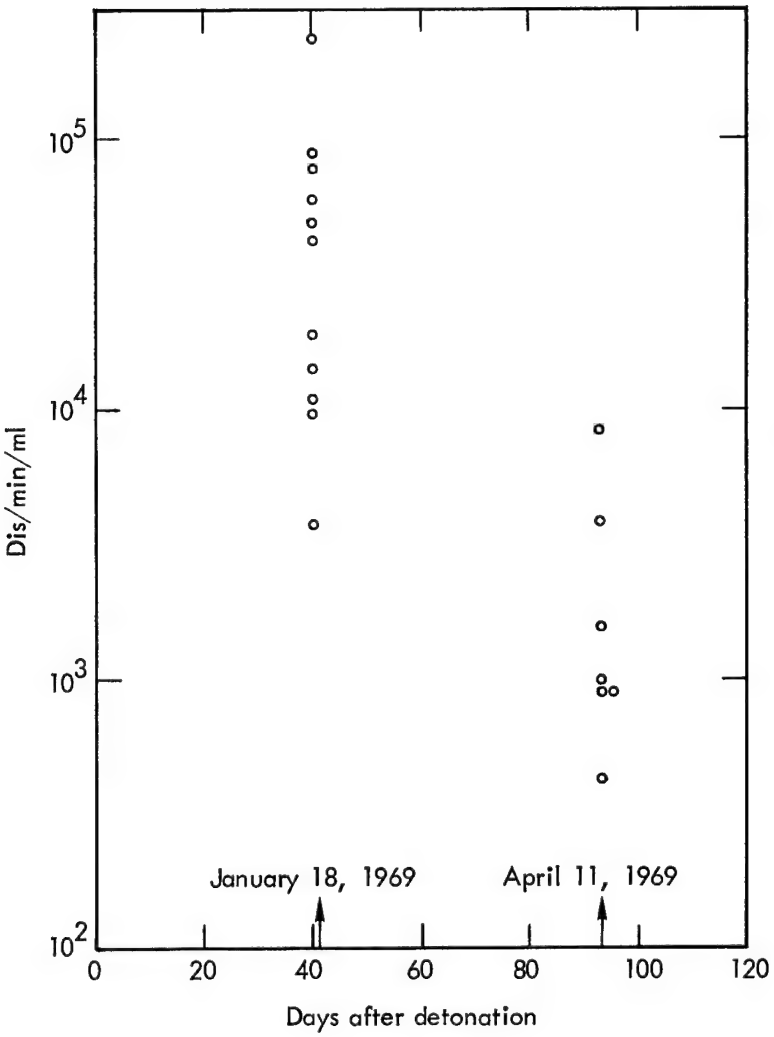

Fig. 40. Tritium concentrations in the body water of small mammals collected at 3000 ft from GZ.

Table 5. Concentration of ^{181}W in dry ejecta from Schooner crater. Sampled January 9, 1969.

Depth (in. below surface)	Concentration (dis/min/g of dry ejecta)	
	800 ft from crater	1465 ft from crater
0	1.25×10^7	1.83×10^7 1.74×10^7
3-5	—	1.11×10^7 1.17×10^7
6-8	9.60×10^5	—
12	5.88×10^6	2.85×10^5 3.36×10^5

These data indicate that at 800 ft from the crater, about 5 percent of the surface ^{181}W activity was found at a depth of 1 ft in the ejecta, but at 1465 ft, only about 1.7 percent of the surface ^{181}W activity was present at the same depth. Apparently, ^{181}W, being volatile at the time of cavity rupture and venting, is scavenged effectively by the fine particles that remain airborne for longer periods; these settle on the already-deposited bulk ejecta, producing high concentrations of this radionuclide on the surface of the ejecta field. If this is the case, then at greater distances from GZ, where only the fine particles are deposited as missile ejecta and close-in fallout, the specific activity (dis/min per gram of ^{181}W should differ very little from that seen on the crater lip. The ^{181}W activities in surface ejecta deposited around GZ to a distance of 3000 ft are shown in Fig. 41. These data were obtained from shovel samples obtained on 9 January 1969. The range of their collection embraces only one-half of the ejecta field, but it can be seen that ^{181}W concentrations in surface ejecta (at depths of 0 to 2 in.) are generally about 10^7 dis/min per gram of dry ejecta; the average of this series was 1.24×10^7 dis/min per gram.

Fallout tray samples were also obtained and analyzed for gamma radioactivity. At this time only ^{181}W data are presented. Figure 42 shows the specific activities of ^{181}W in fallout samples obtained from 2×2 ft trays located on arcs from 3000 ft to 17 miles along the azimuths on which the trays were collected. The mean concentration of ^{181}W is 1.68×10^7 dis/min per gram of dry ejecta. Along the azimuth of the hot line there is an indication that the specific activity of ^{181}W at distances from one to two miles from the crater may be greater than in the surface ejecta around the crater. This kind of fractionation is known to occur for ^{137}Cs, and the apparent volatility of ^{181}W suggests that a fractionation effect may also be demonstrable in its distribution in nuclear crater ejecta. It is apparent from these data that concentrations as high as 9.4 μCi per gram of ejecta may be deposited

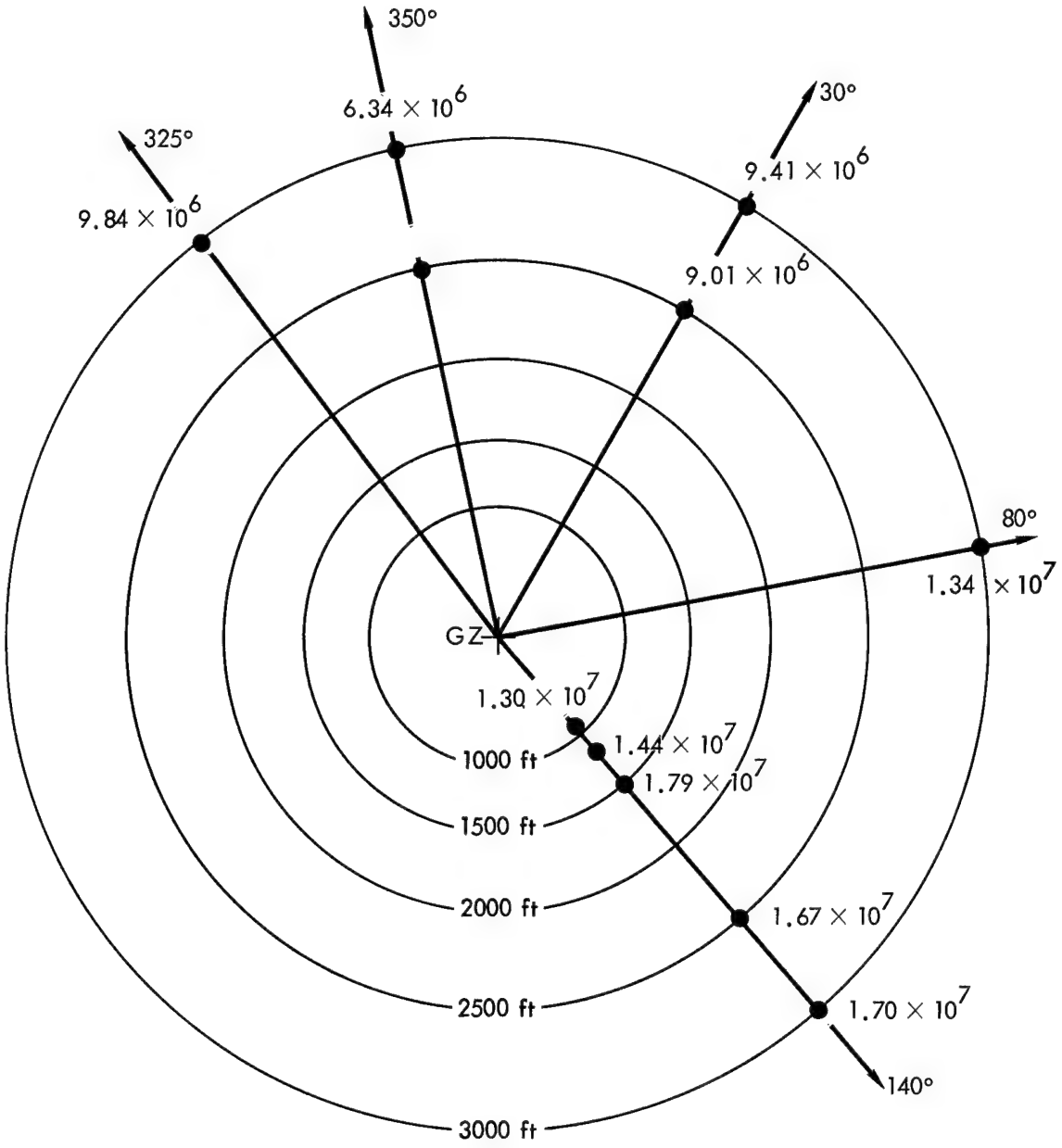

Fig. 41. Concentrations of ^{181}W in surface ejecta from the crater lip to 3000 ft. The data are in dis/min/g; N = 0 deg.

at distances as far as 17 miles from the detonation site.

^{181}W IN TISSUES OF SMALL MAMMALS LIVING AT THE EDGE OF THE SCHOONER EJECTA FIELD

Small mammals such as the pocket mouse (Perognathus sp.) and the kangaroo rat (Dipodomys ordii) were living in the area around the pre-Schooner site. After the detonation, continuous ejecta covered the surface of the ground to a distance of 3000 to 3500 ft from GZ. At the edges of the ejecta field, where ejecta depths were between 2 and 6 in., these rodents dug out of their ejecta-covered burrows and foraged in the postshot environment. They undoubtedly ingested food (seeds)

covered with radioactive particles, and also ingested particles directly as they preened their pelts, which they do daily. Two samples of these small animals were obtained at times up to 125 days after detonation. Their carcasses were freeze-dried and the body water was extracted for tritium analysis. Before freeze-drying, the body cavity of each animal was carefully opened and the stomach, GI tract, liver, kidneys, lungs, and a muscle sample were excised, with a separate set of dissecting instruments for each such dissection. The organs were freeze-dried with the carcasses. The bones, which were easily picked from the freeze-dried

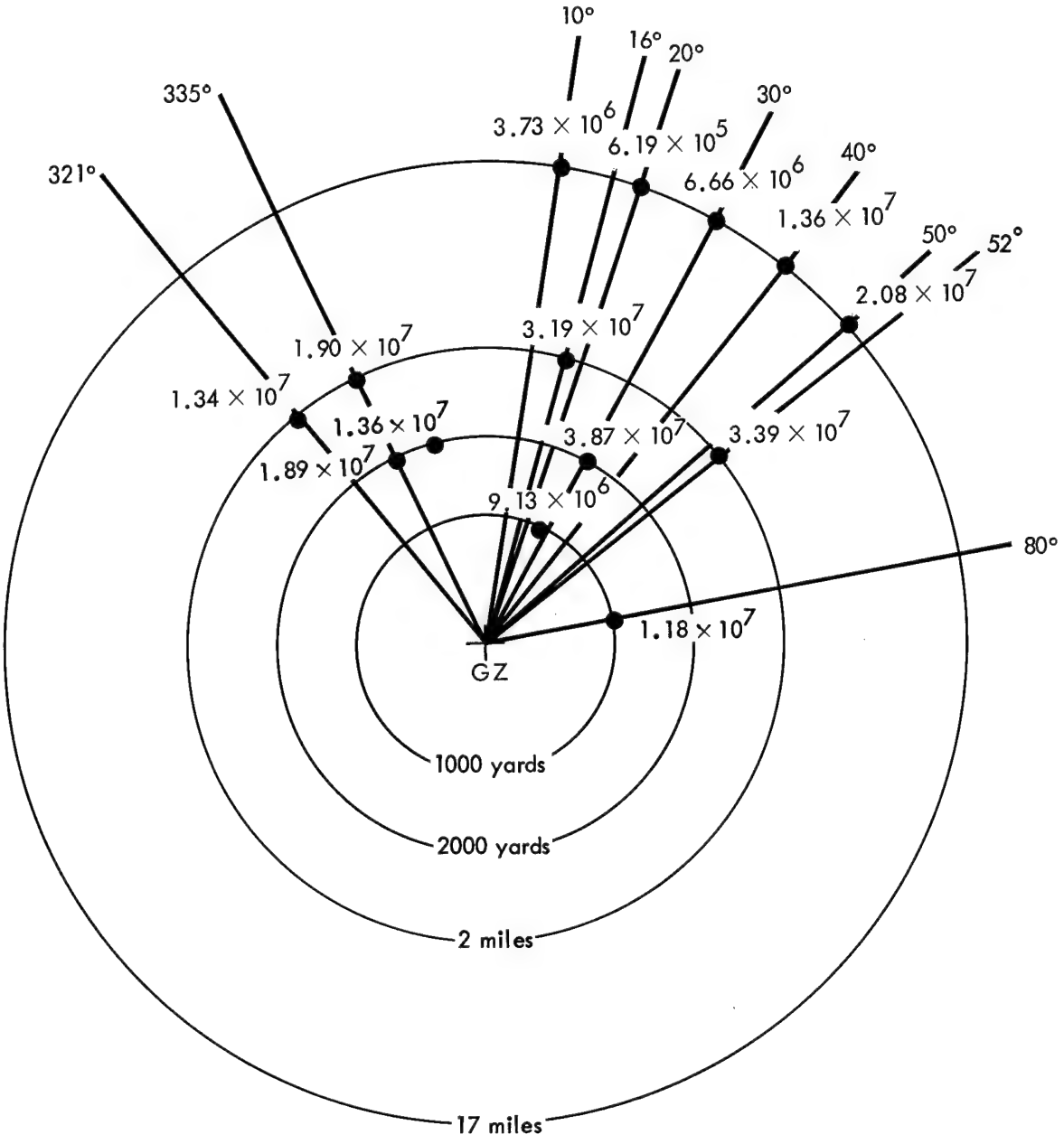

Fig. 42. Concentrations of ^{181}W in ejecta and debris from 1000 yards to 17 miles from GZ. Data are in dis/min/g; N = 0 deg.

Table 6. Concentrations of ^{181}W in the tissues of small mammals collected 3000 ft from the Schooner GZ.

Tissue	Concentration (dis/min/g)[a]	
	Perognathus	Dipodomys
Stomach and GI tract	1.2×10^6	3.4×10^6
Liver	7.7×10^4	2.3×10^5
Kidney	6.3×10^4	2.4×10^5
Lung	5.8×10^4	1.7×10^5
Skeletal muscle	—	1.4×10^4

[a]Per gram dry weight of tissue; values corrected to zero time.

carcass residues, were pre-ashed in a muffle furnace at 250° C overnight to remove all traces of muscle and organ fragments. The pre-ashed bones were then washed and placed in standard counting vials, and assayed for ^{181}W by NaI scintillation counting. Counting efficiencies for ^{181}W in this geometry in a well crystal ranged from 50 to 60 percent.

The concentrations of ^{181}W in the organs of Perognathus and Dipodomys are shown in Table 6. No special significance is given to the values for the different genera of rodents but the data are separated. In the area in which these animals were trapped, the specific activity of ^{181}W was 1.70×10^7 dis/min per gram of dry ejecta. It appears that they were ingesting approximately 0.1 to 0.2 grams per day of ejecta if the ^{181}W concentration in the stomach is any indication of their daily intake. The ^{181}W is apparently absorbed across the intestinal mucosa with ease; concentrations between 5 and 10 percent of those in the ejecta are found in the liver and kidneys, indicating that the radionuclide is being transported by the circulatory system. In laboratory studies of ^{181}W uptake and excretion, Silva et al.[23] found that at 48 hr, between 2.5 and 3.0 percent of the injected or ingested ^{181}W activity was in the bones of mature white rats. This fraction of the administered dose was higher than in any other organ in the body at that time.

The small mammals living at the edge of the Schooner ejecta field were ingesting debris and radioactive particles containing a high concentration of ^{181}W, which was shown to be biologically available to the animal by its presence in visceral organs. To determine whether the high bone concentrations of ^{181}W also would occur under natural conditions, when the animals were ingesting radioactive particles produced in a nuclear cratering event, and under equilibrium conditions of chronic ingestion, the bones of two samples of animals obtained between 40 and 125 days after detonation were assayed for ^{181}W. The concentrations of ^{181}W per gram of bone (unashed) for two samples of small mammals living at 3000 feet from Schooner GZ are shown in Fig. 43. The range of concentrations observed in the first sample embraces almost two orders of magnitude. Apparently all of the animals trapped in this sample, although living at approximately the same distance from the Schooner GZ,

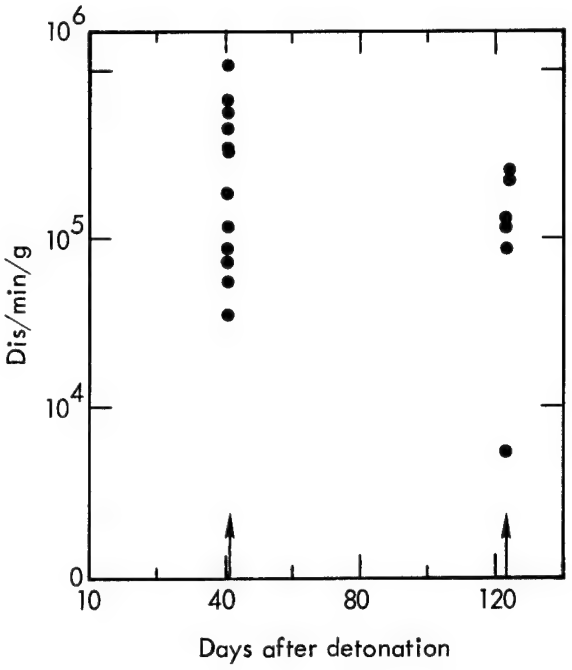

Fig. 43. Concentrations of ^{181}W in the bone of small mammals collected at 3000 ft from GZ.

were not ingesting the same amount of radioactivity. This wide range of ^{181}W bone concentrations may also be caused by differences in the ages of the animals and individual variations in their metabolism of tungsten. For the second sample, the values lie mainly within the range of the first sample, but the number of animals obtained was smaller. Only when data from continuing studies are available will more detailed statements on the population levels and changes be possible. If the 40-day sample represents an equilibrium condition, then it appears that approximately 1.7 percent of the ^{181}W activity per gram of debris is present per gram of bone. A value of 2.94×10^5 dis/min per gram of bone was used as a mean value for the 40-day postshot sample. This concentration, which is equivalent to 0.13 μCi per gram of bone, would produce an integrated dose of between 15 and 20 rads to the animal if no other exposure occurred after this level was attained.

Biological Availability to Dairy Cows of Radionuclides in Schooner Debris

Gilbert D. Potter, David R. McIntyre,
and Gerald M. Vattuone

ON-SITE CYCLONE PARTICLE SEPARATOR

Two of these devices (Sadsac) were designed and fielded by our engineering and support group (this report, p. 29). The purpose of this experiment was to test the feasibility of collecting at close range a large amount of fallout particles in specific particle-size groups (resembling those of more distant fallout) without such complications as the agglomeration of small particles. The particles so collected would be fed to animals to test the biological availability of radionuclides in the debris. Further, the nuclide compositions of various fractions could be compared to confirm studies on the physical and chemical parameters of fallout particles as a function of size. From preliminary observations, it appears that these collectors did operate according to theory. However, the 20- to 100-μ particles appeared to dominate all others and all fractions appeared to be somewhat similar. It appears that a large-volume collector could be of value but might better be designed to collect only a single large sample. The advantage appeared to be in the collection of a large sample of material relatively free from other contaminants and kept dry until retrieved. The main disadvantage was that the collectors were in high radiation areas and could not be retrieved at early times as was expected. Debris from one of these collectors was fed to a pregnant cow as described below.

Table 7. Debris radionuclides in feces, urine and milk following oral administration of Schooner debris to a lactating cow.

	% administered dose		
Nuclide	Feces	Urine	Milk
^{54}Mn	84	ND[a]	ND
^{58}Co	88	ND	ND
^{74}As	49	29	0.002
^{88}Y	104	2	ND
^{89}Zr	74	ND	ND
^{99}Mo	91	7.8	1.0
^{103}Ru	106	8.0	ND
^{131}I	45	36	2.2
^{132}Te	101	1.5	0.08
^{140}Ba/^{140}La	107	0.06	0.06
^{181}W	65	10.4	0.3
^{187}W	101	10.7	0.22
^{188}W/^{188}Re	80	34	0.43
^{196}Au	98	ND	ND
^{203}Pb	106	ND	ND

[a]ND: not detected.

BIOLOGICAL AVAILABILITY OF RADIONUCLIDES IN THE DAIRY COW FED DEBRIS FROM SCHOONER

Approximately 200 g of debris from a fallout tray from the Schooner Event was

fed to a lactating cow. Milk, blood, urine, and feces were collected for a 7-day period. The biological samples were analyzed on a 2048-channel analyzer used in conjunction with a GeLi detector. Calculations of the recovery of individual radionuclides from this experiment are underway. Preliminary results (Table 7) show debris radionuclides in metabolic products as percentages of the administered dose. The data are only preliminary and subject to change, but the analysis of the data is nearing completion. The results will be presented in detail in a forthcoming report.

MATERNAL-FETAL TRANSFER STUDY OF RADIONUCLIDES IN DEBRIS FED TO A PREPARTUM COW

Approximately 1 kg of debris from the cyclone separator Sadsac (particle size 20 to 100 μ) was fed to a pregnant cow over a 5-day period. On the 7th day the cow was killed and representative samples of tissue were taken from both cow and fetus. Since the cow was still lactating at the time she was fed debris, a milk-urine-plasma-feces study was also carried out. All samples were analyzed with a GeLi diode for individual radionuclides. Reduction and analysis of the data are still underway.

Biological Availability to Pigs of Radionuclides in Schooner Debris

Robert J. Chertok, Susanne Lake, Joseph W. Serpa,
John M. Dawson, and Barry Brunckhorst

INTRODUCTION

Three experiments were conducted to determine the biological availability to pigs of radionuclides in Schooner debris. Pigs were chosen as the experimental animal both because of their importance as a meat source and because of the close similarity of their gastrointestinal physiology to that of man.

PROCEDURE

The first experiment was a field study in which two domestic pigs were housed in a metabolic cage (Fig. 44) at Stations 5, 6, 8, and 11 (see Fig. 10 for locations of stations). Feed was placed in large open trays by each cage so as to be contaminated by fallout. A sequentially operated battery of filters was placed at each station to document qualitatively and quantitatively the airborne radionuclides present at various intervals during the course of the experiment.

Samples of urine and feces were collected at Stations 6 and 8 daily from D + 1 day to D + 8 days. At D + 8 days the pigs

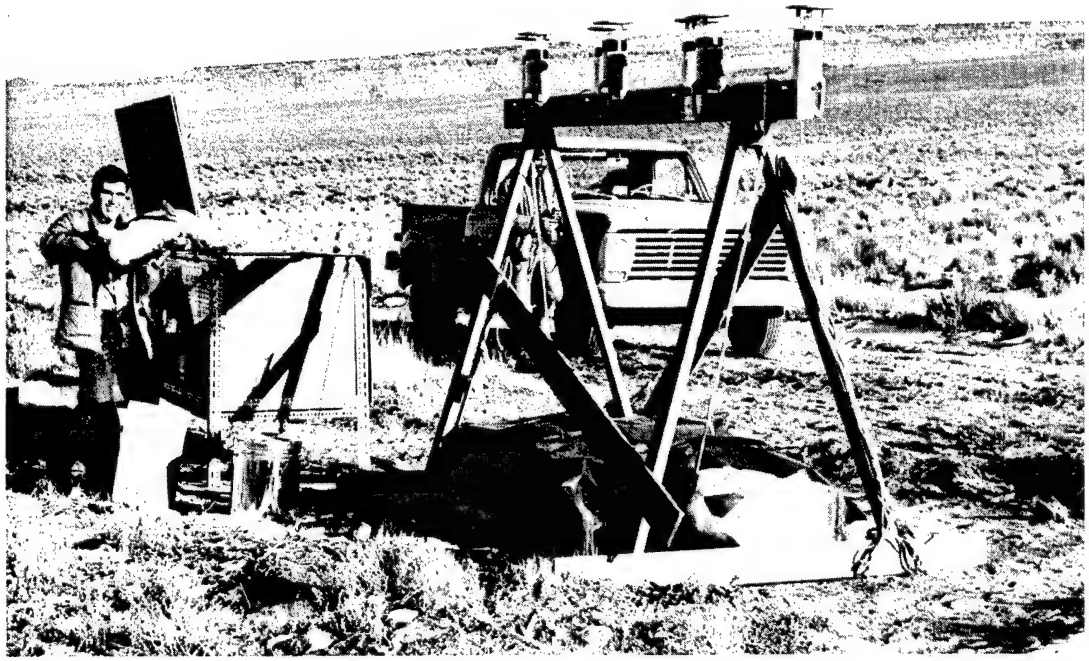

Fig. 44. A swine station at the site. Each of these stations was located next to a sequential air-sampling station.

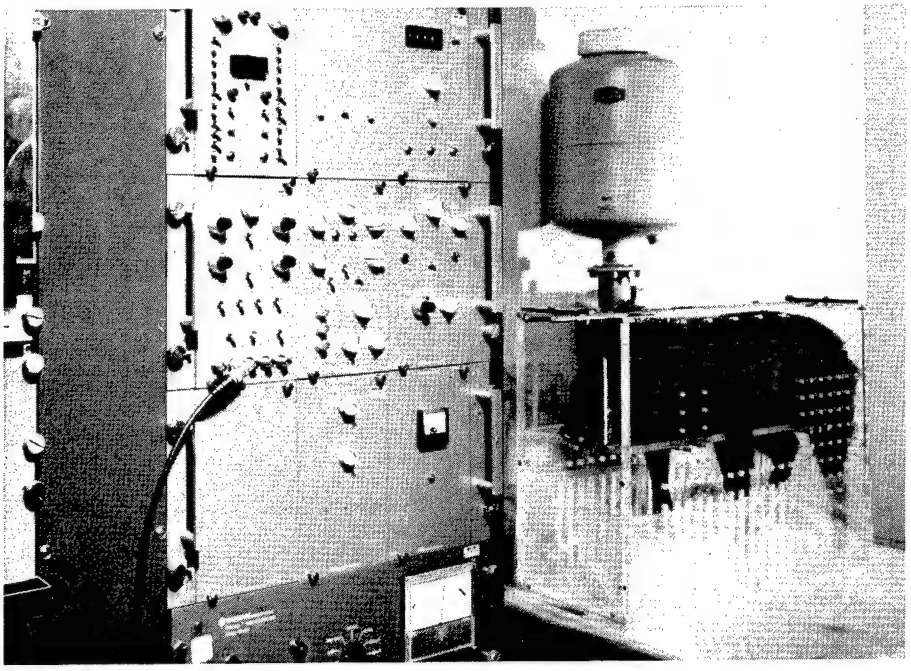

Fig. 45. The solid-state whole-body counter used to count the pigs fed Schooner debris. The pig is at the far right in a constraint box.

were transferred from the field to the laboratory and killed. Their organs were removed and prepared for analysis of the gamma-ray emitting radionuclides. On D + 1 day the radiation field at Station 11 only permitted the feeding and watering of the animals. On D + 2 days accessibility to Stations 5 and 11 was prohibited. On D + 3 days, urine and feces samples were collected at both stations and the animals were taken to the laboratory, killed, and dissected. Consequently, urine and feces samples were collected for Station 5 only on D + 1 and D + 3 days and at Station 11 only on D + 3 days.

In the second experiment, debris from the middle fraction (20- to 80-μ particles) collected with the Sadsac collector (this report, p. 29) was administered orally to two peccaries. These pigs were housed in metabolic cages and daily urine and feces samples were collected and counted. They were also counted daily in a whole-body counter (Fig. 45). When the whole-body counts reached a very low level the third experiment was initiated. For this study, the same pigs were fed the debris daily until the whole-body counts approached a plateau. As before, urine and feces were collected daily and analyzed. At the conclusion of this experiment the animals will be killed and their organs assayed individually with the high-sensitivity GeLi counting system to determine the body distribution of the radionuclides.

RESULTS

Field Study

The two pigs at Station 11 on Gold Flat received the largest doses of radiation. Figure 46 gives the readings from the nearby air-sampling station. Only these pigs will be reported on here; the results

are preliminary and subject to change. These pigs were kept at their station approximately three days after detonation, during which time they could be serviced only once because of the high radiation field. When they were removed from the field they appeared to be ill, and one died several hours before scheduled for killing and dissection. The organs were analyzed individually for radionuclide concentrations and the values were corrected for physical decay to zero time.

The major radionuclides seen in the tissues were ^{99}Mo, ^{132}Te, ^{203}Pb, ^{196}Au, ^{131}I, ^{198}Au, ^{103}Ru, ^{74}As, and ^{187}W. All of these radionuclides were found in the lungs (Table 8). Prior to analysis, each lung was divided into upper and lower sections. For all the radionuclides, there appeared to be some compartmentalization within the lung; the reasons were not clear. Since all of the radionuclides were taken in both by inhalation and ingestion, no conclusions

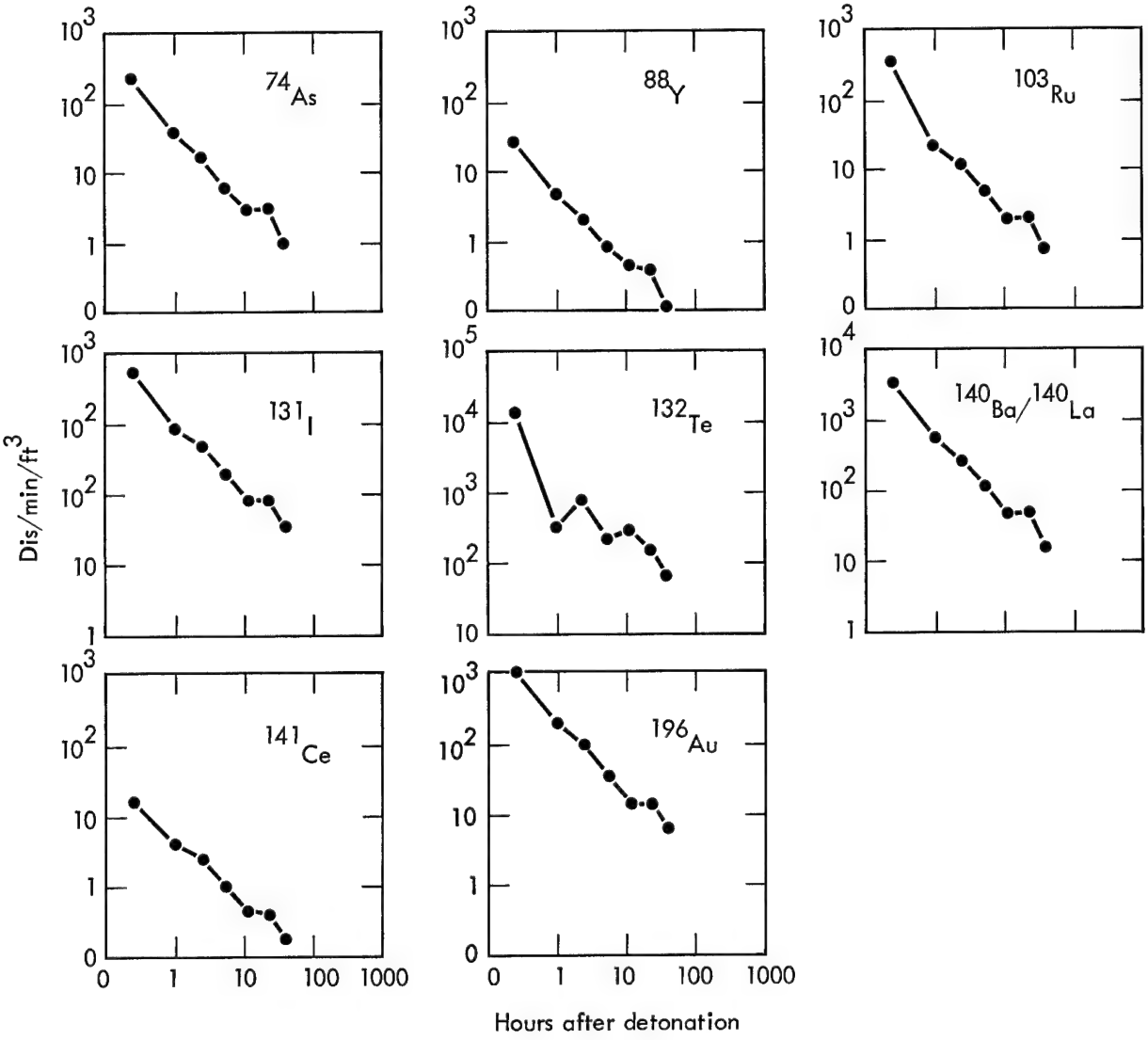

Fig. 46. Air activities of eight radionuclides as a function of time after the Schooner detonation as measured at Station 11.

Table 8. Radionuclide concentrations in lung tissue (dis/min/g of wet tissue) of the Station-11 pigs.

Lung section	^{99}Mo	^{132}Te	^{203}Pb	^{196}Au	^{131}I	^{198}Au	^{103}Ru	^{74}As	^{187}W
Upper right	6.3[a]	91.5[a]	51.2[a]	36.4[a]	34.9[a]	7.1[a]	7.6[a]	18.4[a]	48,700
Lower right	15.2[a]	102	80.0[a]	25.1	31.1	27.0[a]	9.3	19.6	54,500[a]
Total	21.5	193	131	61.5	66.0	34.1	16.9	38.0	103,000
Upper left	ND[b]	134[a]	ND	57.9	44.1	ND	4.3	4.2	ND
Lower left	8.1[a]	131[a]	122[a]	24.1	47.6	29.9[b]	4.9	17.6	107,000[b]
Total	8.1	265	122.	82.0	91.7	29.9	9.2	21.8	107,000

[a]Value based on one determination.

[b]ND: not detected.

Table 9. Radionuclide concentrations (dis/min/g of wet tissue) in the Station-11 pigs.

Tissue	^{99}Mo	^{132}Te	^{203}Pb	^{196}Au	^{131}I	^{198}Au	^{103}Ru	^{74}As	^{187}W
Blood	6.6	94.4	37.2	13.6	35.8	3.7	2.9	6.5	56,200
Thyroid[a]	28.8	44.3	53.3	16.0	29.9	10.9	Tr[+]	6.0	42,100
Trachea[a]	ND[b]	ND	ND	ND	43.9	ND	0	13.3	ND
Sal. gland	12.7	85.4	0	35.1	19.9	0	0	0	42,900
Heart[a]	2.8	19.7	ND	3.4	16.6	ND	ND	4.3	7,880
Liver	258	92.4	0	0	7.7	0	0.4	7.3	36,300
Kidney	308	242	22.9	33.3	22.3	0	18.5	29.9	273,000
Gall bladder[a]	130	90.0	0	55.3	42.7	Tr	Tr	0	50,300
L. intestine	331	1690	3880	1120	306	509	157	107	1,660,000
Brain[a]	1.5	2.1	0	1.6	1.6	0	Tr	1.9	2,600
Muscle	6.7[a]	10.2[a]	4.3[a]	6.0[a]	5.3[a]	0	Tr	7.2	6,250[a]
Bone	ND	ND	ND	ND	0	ND	0	0	ND
Fat	6.6	14.7	13.6	7.9	8.0	1.5	0.6	1.8	13,700

[a]Value based on one determination.

[b]ND: not detected.

may be drawn on the importance of one or the other route of intake.

The data for the other organs are given in Table 9. Since the large intestine by virtue of its function is difficult if not impossible to prepare for analysis, it serves only more or less as a guide to what had been available to the animal via the oral route at the time of death.

It is obvious that ^{187}W was present in very high concentrations in most of the tissues studied, particularly the kidneys. In bone and trachea, it was no longer detectable because of half-life considerations and therefore may or may not have been present.

Of the other radionuclides detected, ^{99}Mo appeared in relatively high concentrations in liver, kidney and gall bladder, $^{188}W/^{188}Re$ in kidney and bone, and ^{132}Te in kidney, blood, liver and salivary gland. The remaining radionuclides were found in lower concentrations. Of these, ^{203}Pb appeared to be more concentrated in the thyroid, blood and kidney, ^{196}Au was concentrated in gall bladder, salivary gland

and kidney. Kidney was the only organ where ^{74}As was concentrated to any extent. The ^{131}I was seen to a greater extent in trachea, gall bladder, blood, thyroid and kidney.

The sequential air-filter data at Station 11 for H + 47 hr are shown in Fig. 46 for ^{74}As, ^{88}Y, ^{103}Ru, ^{131}I, ^{132}Te, $^{140}Ba/^{140}La$, ^{141}Ce, and ^{196}Au. Activities above the expected levels were measured during the interval from H + 15-1/2 hr, to H + 31-1/2 hr, probably because of resuspension and redistribution of previously deposited debris by high winds.

Acute Feeding of Debris

The predominant radionuclides in the Sadsac debris used for the second experiment were $^{188}W/^{188}Re$, ^{196}Au, ^{131}I, ^{103}Ru, ^{74}As, ^{58}Co, ^{54}Mn and ^{88}Y. The results reported here (Fig. 47) are preliminary and confined to only one of the two pigs used in the experiment.

Most of the ingested $^{188}W/^{188}Re$ was excreted in the feces on the third day; thereafter the rate of excretion by this route decreased rapidly. About 14 percent had been excreted by the kidney by 9 days; about 10 percent of this was excreted during the first day. At the end of the 9 days only 2 percent of the ingested $^{188}W/^{188}Re$ was detected in the animal by whole-body counting.

About 8 percent of the ingested ^{196}Au was excreted by the kidney at a slow rate; about 91 percent was excreted in the feces. At the end of 9 days no ^{196}Au could be detected by whole-body counting.

More than half of the ^{131}I was excreted in the feces, mostly on the third day. Nearly 30 percent was excreted by the kidney, with a high rate of excretion on the first day.

The excretion pattern of ^{74}As was very similar to that of ^{131}I in that nearly 37 percent was excreted by the kidney, almost 30 percent of this on the first day. Again, most of that excreted in the feces was found in the third-day sample. About 5 percent remained in the animal at the end of 9 days.

The excretion patterns for ^{103}Ru, ^{58}Co, ^{54}Mn and ^{88}Y were very similar. Less than 2 percent of each radionuclide was excreted in the urine. Again, most of each radionuclide was excreted on the third day in the feces. Small amounts of these radionuclides were detected by whole-body counting of the animals after 9 days.

Some of the irregularities in the whole-body counts seen in the graphs can be explained by a change in the geometry between the radionuclide and the detector. Even though the positioning of the animal with respect to the detector was constant, the position of the radionuclide changed as a result of distribution within the body of the pig.

CHRONIC FEEDING OF DEBRIS

The chronic feeding experiment is still in progress. The results will be available in the near future.

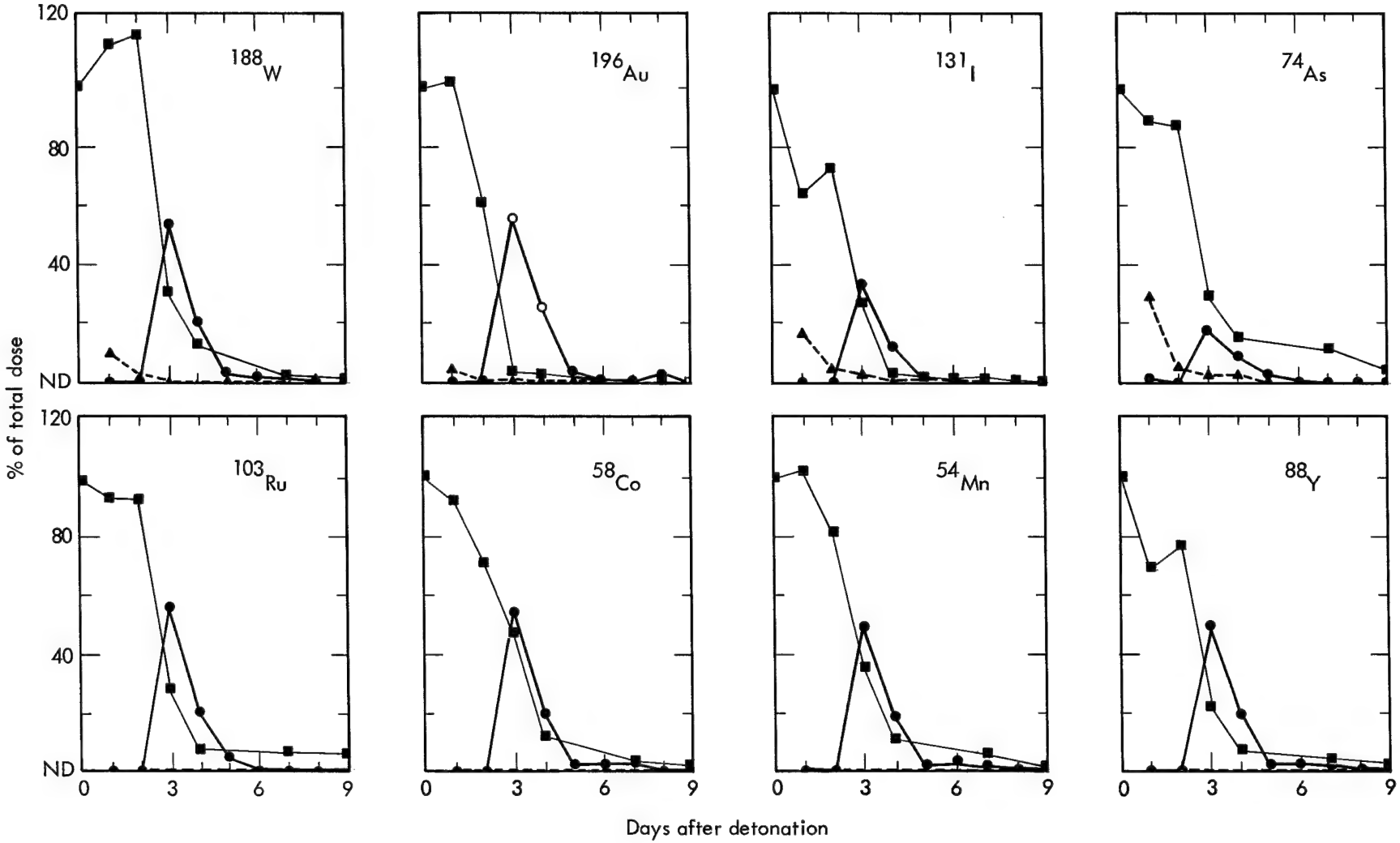

Fig. 47. Whole-body retention and excretion of eight radionuclides in Schooner debris after an acute feeding experiment. ND, not detected; circles, fecal excretion; triangles, urinary excretion; squares, whole-body values.

Studies in Aquatic Biology

Florence L. Harrison, Jane M. Ott, and
Dorothy J. Quinn

INTRODUCTION

This program has two objectives:

1. To assess the biological availability of Schooner debris radionuclides to marine and freshwater animals in man's food chain.
2. To examine some of the physical and chemical characteristics of nuclear debris to determine how they affect the biological availability of the radionuclides.

Two series of experiment were planned for Schooner. The first series was conducted on fallout material collected on the hot line about 3000 ft from ground zero. The second series is being conducted on crater-lip material collected at the time of the exploration of the crater lip.

EXPERIMENTS WITH FALLOUT MATERIAL

Physical and Chemical Characteristics

Some of the physical and chemical characteristics of the debris radionuclides have been evaluated.

The debris was separated into different size fractions to investigate the effect of particle size on radionuclide content and leachability. Approximately 500 g of debris was dried and then fractioned in a sieve shaker. The particle-size distribution of the material is presented in Table 10. Over 50 percent of the mass of the material consisted of particles < 250 μ in diameter. Since this fallout sample was collected from the ground surface several weeks after the event, the initial particle-size distribution may have been modified by local wind action.

The radionuclide concentration was determined in aliquots of the various particle-size fractions of the debris (Table 11). Two patterns of variation in concentration with particle size are seen. For ^{54}Mn, ^{58}Co, and ^{88}Y, concentration increased with increased particle size except for the $> 1000 < 4000$ μ fraction (Fig. 48), apparently indicating that these radionuclides were volume-distributed. For ^{74}As, ^{103}Ru, ^{110m}Ag, $^{140}Ba/^{140}La$, and $^{188}W/^{188}Re$, concentration decreased with increased particle size, indicating that these radionuclides were surface-distributed.

The leachability of the debris radionuclides was determined in various aqueous solutions: distilled water, synthetic pond water, synthetic seawater, 0.1 N HCl, and 1.0 M ammonium acetate. Approximately 7 g of debris was added to 150 ml of the

Table 10. Particle-size distribution in Schooner fallout debris used for biological availability experiments.

Microns	% of total
>4000	19.7
4000 - 1000	12.0
1000 - 250	10.7
250 - 62	23.7
<62	33.9

solution in a closed plastic container. The mixture was shaken for 48 hr on a rotary shaker at 230 cycles/min and centrifuged, and then the supernatant was filtered through a 0.45-μ Millipore filter. The filter and debris were counted separately from the water.

Table 11. Radionuclide concentration in size fractions from sieved Schooner debris.

	Concentration (μCi/kg)			
	Particle fraction (μ)			
	<4000 >1000	<1000 >250	<250 >62	<62
$^{140}Ba/^{140}La$	2.7[a]	28[a]	27[b]	31[b]
^{74}As	2.0[a]	9.0[a]	4.4[a]	18[b]
^{103}Ru	1.9[b]	5.4	7.2	15
^{106}Ru	ND[c]	ND	ND	0.86[a]
^{110m}Ag	0.11[a]	0.36[b]	0.59	0.95
^{58}Co	15	24	30	9.5
^{54}Mn	3.9	7.6	6.3	1.9
^{88}Y	1.8	3.6	1.8	0.45

[a]FSD (fractional standard deviation) > 0.5. The FSD is the standard deviation of the count value divided by the number of counts.

[b]Fractional standard deviation between 0.2 and 0.5.

[c]ND: not detected.

Leaching distribution coefficients $K_{d,\ell}$ in synthetic pond water and seawater were determined on aliquots of the four smaller particle-size fractions. The $K_{d,\ell}$ is defined as

$$K_{d,\ell} = \left[\frac{f_d}{(1 - f_d)}\right]\left(\frac{V}{W}\right)$$

where

f_d = fraction of the activity in the solid phase,

$1 - f_d$ = fraction of the activity in the liquid phase,

V = volume of liquid in ml,

W = weight of the debris in g.

Table 12 gives the $K_{d,\ell}$ values determined in pond water for the various particle-size

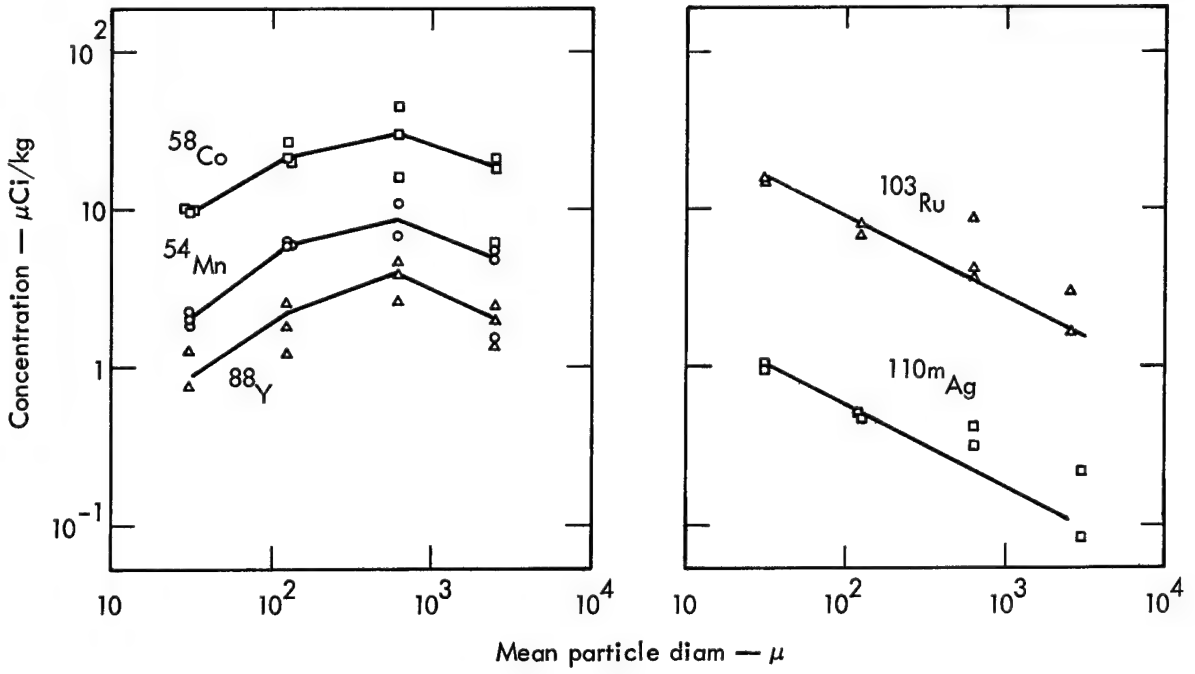

Fig. 48. Radionuclide concentrations in Schooner debris as a function of particle size. Left, ^{54}Mn, ^{58}Co, and ^{88}Y. Right, ^{103}Ru and ^{110m}Ag.

Table 12. Leachability of debris radionuclides in synthetic pond water.

	$K_{d,\ell}$ (ml/g)			
	Particle fraction (μ)			
	>1000	<1000 >250	<250 >62	<62
^{74}As	140[a]	160[a]	24[a]	120[b]
	210[a]	260[a]	30[a]	
^{88}Y	14,000[b]	9,000[b]	2,700[b]	ND
	14,000[b]	ND[c]	ND	ND
^{103}Ru	410[b]	1,100	900	930
	1,200[b]	1,700	710	920
$^{140}Ba/^{140}La$	210[a]	960[a]	ND	ND
	140[a]	ND	ND	ND
$^{188}W/^{188}Re$	300	360	170	140
	350	300	160	140

[a]Fractional standard deviation >0.50.

[b]Fractional standard deviation between 0.20 and 0.50.

[c]ND: not detected.

Table 13. Leachability of debris radionuclides in synthetic seawater.

	$K_{d,\ell}$ (ml/g)			
	Particle fraction (μ)			
	>1000	<1000 >250	<250 >62	<62
^{74}As	11[a]	210[a]	29[a]	96[b]
	98[a]	430[a]	18[a]	79[b]
^{88}Y	10,000[b]	9200[b]	9000[b]	ND[c]
	35,000[b]	9600[b]	ND	ND
^{103}Ru	220[b]	540	450	780
	900[b]	1400	450	860
$^{140}Ba/^{140}La$	15[a]	650[a]	116[b]	84[b]
	33[a]	680[a]	64[b]	159[b]
$^{188}W/^{188}Re$	280	250	95	80
	220	220	94	83

[a]Fractional standard deviation >0.50.

[b]Fractional standard deviation between 0.20 and 0.50.

[c]ND: not detected.

fractions. The effect of particle size differed with radionuclide. The $K_{d,\ell}$ decreased with decreased particle size for ^{88}Y and $^{188}W/^{188}Re$ but seemed to change little for ^{103}Ru.

Table 13 gives the $K_{d,\ell}$ values determined in synthetic seawater. The effect of particle size was very similar to that in pond water; the ^{88}Y and $^{188}W/^{188}Re$ values decreased with decreased particle size and the ^{103}Ru values showed little change.

The leachability of the debris radionuclides associated with the <62-μ size fraction was determined in five solutions (Table 14). For most of the radionuclides, concentrations were so low in pond water that they could not be detected with our counting system. Except for $^{188}W/^{188}Re$, the $k_{d,\ell}$ values were lower in 0.1 N HCl than in the other solutions. This solution approximates the pH of the digestive fluid of many animals and gives an indication of the leachability of debris radionuclides introduced into the gut. The $^{188}W/^{188}Re$ appears to be more soluble at the higher pH (distilled water approximately 7, seawater and pond water approximately 8).

Biological Availability

The biological availability of the fallout debris radionuclides to freshwater and marine bivalve molluscs is being assessed. Approximately 200 g of intact debris was placed in a leaching column 15 cm in diameter and 160 cm long. Water from an 80-liter aquarium was circulated continuously up through the column at a rate of about 1.5 liter/hr (Fig. 49). Data from these experiments will be presented later; the counting of the samples is still under way.

Table 14. Leachability in various aqueous solutions of debris radionuclides of the <62 size fraction.

	Synthetic pond water	Synthetic seawater	0.1 N HCl	Distilled water	1.0 N Ammonium acetate
^{54}Mn	ND[a]	ND	1100[b]	ND	ND
^{58}Co	ND	ND	650	ND	ND
^{74}As	120[b]	90[b]	50[b]	60[b]	20[b]
^{88}Y	ND	ND	1500[c]	220[c]	ND
^{103}Ru	920	820[b]	30	1100[c]	70
^{106}Ru	ND	ND	50[c]	ND	23[c]
^{110m}Ag	ND	130[b]	50	ND	ND
$^{140}Ba/^{140}La$	ND	120[c]	30[b]	ND	30[b]
$^{188}W/^{188}Re$	140	80	1800	70	170

[a]ND: not detected.

[b]Fractional standard deviation between 0.2 and 0.5.

[c]Fractional standard deviation >0.50.

EXPERIMENTS WITH CRATER LIP MATERIAL

The Plowshare Division of LRL has excavated a trench in the immediate region of the crater lip of Schooner. Several tons of debris were collected from the crater lip region for long-term studies of biological availibility. In addition, this debris may be used for column-leaching studies.

Physical and Chemical Characteristics

Some of the physical and chemical characteristics of the crater-lip debris will be evaluated. Particles will be sized and their radionuclide concentration determined and investigated as with the fallout material. The leachability of the intact and sieved debris will be assessed in various aqueous solutions by the previously described method.

Crater-lip debris samples will be placed in leaching columns, and seawater will be percolated through them at varying rates. Not only will the rates of movement of radionuclides in solution be assessed, but also the possible movement of small radioactive particles through channels in the debris mass.

Biological Availability

Long-term experiments were initiated with the debris obtained from the crater lip. Approximately 1 ton of debris was added to a pool containing 2000 gallons of seawater. A marine ecosystem will be established with representative marine animals used as food by man. The changes in radionuclide concentration will be followed in animals, water, and debris for 1 to 2 years. In addition, comparable

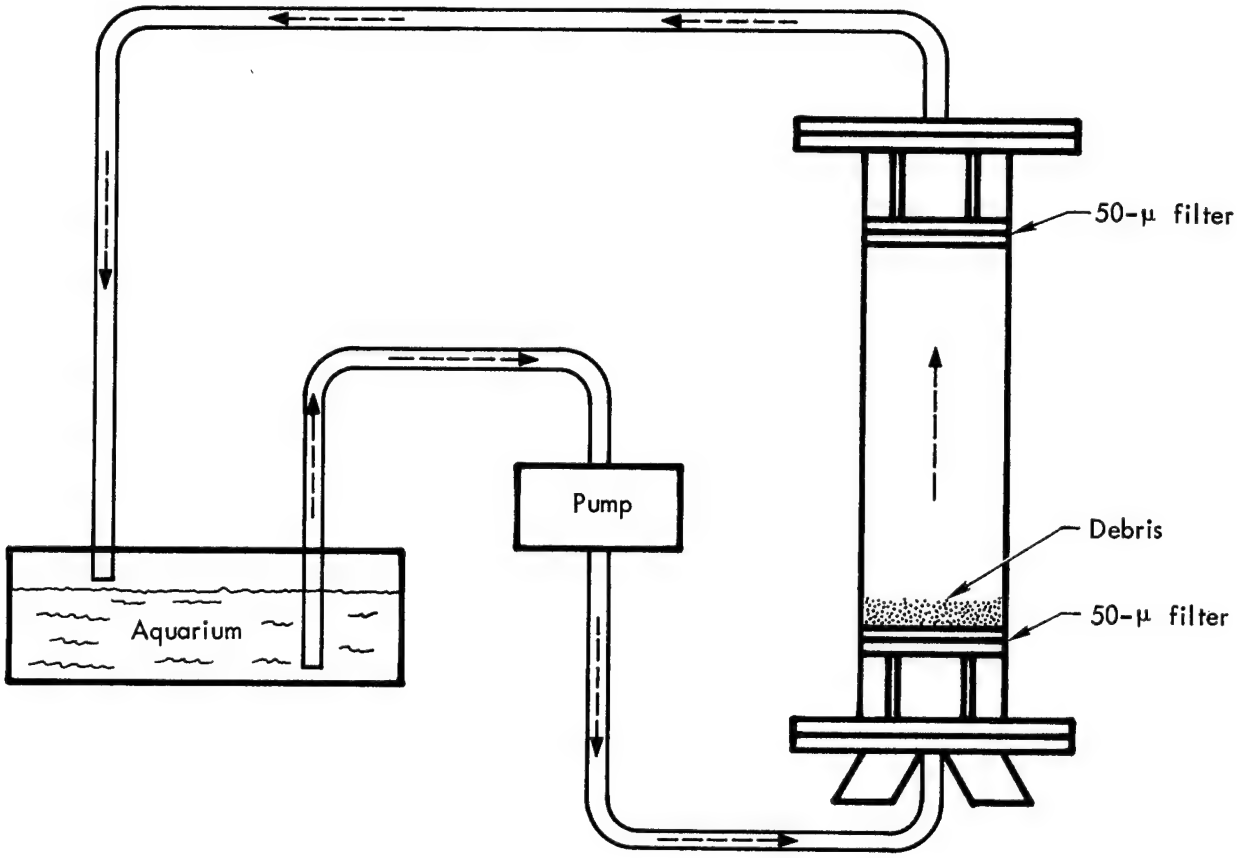

Fig. 49. Diagram of the system for determining the biological availability to aquatic organisms of radionuclides in debris.

quantities of debris were added to a pool containing 2000 gallons of fresh water. The pool will be stocked with edible fresh-water organisms and the water, debris, and animals will be sampled at specific intervals for 1 to 2 years.

Ecological Studies at Far-Out Locations

Robert J. Grabske and John M. Dawson

Samples of surface soil were collected on an approximate 50-mile arc from the Schooner detonation site on 14 May 1969 and again on 30 May 1969 (D + 157 and D + 173 days). The samples were taken along U.S. Highway 6 from the Tonopah Airport on the west to Warm Springs on the east, along Nevada State Highway 25 from Warm Springs on the north to Queen City Summit on the south, and off the highway in the Reveille and Railroad Valleys. In addition to the soil samples, vegetation (sage) and water from streams and ponds were also collected.

The soil samples were collected by removing 1 in. of soil from the surface. They were prepared for counting by sifting to remove particles greater than 1 mm in diameter and packing in tuna cans for constant counting geometry. The plant samples were trimmed to remove all material except the fresh green growth, freeze-dried, and similarly pressed into tuna cans for counting. The water samples were filtered through Whatman No. 42 filter paper and sealed in tuna cans for counting. The ^{181}W activity was determined by NaI scintillation counting, and the other activities were assayed with a GeLi counting system. The absolute activities were determined by comparing sample counts with appropriate standards and correcting for physical decay to the date of collection. The soil data were expressed in terms of $\mu Ci/m^2$.

The ^{181}W was the predominant source of gamma radiation in all of the soil samples that were collected, contributing more than 96 percent of the total gamma activity. The other significant gamma emitters, other than natural radioactive isotopes, were $^{188}W/^{188}Re$, ^{88}Y, ^{182}Ta, ^{137}Cs, ^{103}Ru, ^{110m}Ag, ^{141}Ce, and ^{60}Co. A detailed listing of these activities will be presented later.

The ground distribution of radioactivity at the time these collections were made was clearly a reflection of the path of the main cloud as opposed to the base surge. A relatively small amount of activity was found to the north of the detonation site whereas relatively high concentrations of activity were found to the east (Table 15).

At the time of collection, water was flowing in Hot Creek and numerous streams were flowing in the Reveille Valley, being fed from melting snow in the Kawich Range. Samples of water were collected from these sources, but no gamma activity was detected in any of the 250-ml samples.

The radioactivity found on the vegetation was predominantly from ^{181}W and was relatively high in those areas where the soil activity was high. At Queen City Summit, where the highest concentrations of ^{181}W were found in the soil, the new growth on the sage brush contained 1460 pCi of ^{181}W per gram dry weight of foliage. The relative amount of activity that was surface-deposited on the plants as dust, as opposed to the activity incorporated into the plant tissue, has not been established. Since 66 percent of the ^{181}W activity could be removed by rinsing the fresh plants with a mild saline solution,

Table 15. ^{181}W activity in soil samples.

Location	Azimuth	Distance from GZ (miles)	^{181}W activity ($\mu Ci/m^2$)
Tonopah Airport	30° W	57.6	0.3
Stone Cabin Valley	1° W	54.9	4.1
Hot Creek Valley	14° E	72.3	0.6
Near Warm Springs	13° E	59.8	0.7
Near Twin Springs	24° E	61.0	1.4
Railroad Valley (dry pond)	30° E	53.7	1.0
Railroad Valley (dry lake)	33° E	52.7	1.6
Reveille Valley	14° E	51.8	0.7
Reveille Valley (Reveille Mill)	14° E	46.6	1.3
Reveille Valley	22° E	41.5	1.8
Railroad Valley (ranch)	40° E	37.1	6.2
Reveille Valley	36° E	34.0	38.5
Railroad Valley	44° E	41.0	54.7
Queen City Summit	51° E	44.8	570

surface deposits probably accounted for a significant fraction of the total activity.

Samples of cow manure collected in the southern part of the Reveille Valley contained 5.4 μCi of ^{181}W per kilogram dry weight. This indicated that livestock in that area were exposed to radioactivity probably by grazing on contaminated foliage. The chemical nature of the tungsten, whether it be inorganic material surface-deposited on the plants or in an organic form within the plants, would undoubtedly play a significant role in its biological availability.

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